DROUGHT ASSESSMENT OF PAKISTAN AND ITS IMPACT ON ITS AGRICULTURAL PRODUCTION

BY

MUHAMMAD ALI KHAN

THESIS

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Adviser:

Professor Ximing Cai

ABSTRACT

Growing population and climate changes have raised concerns for the food security. There is a growing interest in studying climatic variables which include precipitation & temperature and their impacts on the crop yield. Crop production with comparison to yield is a more suitable and realistic variable for such an analysis because drought impacts both the crop yield and harvesting area. Agriculture is an important sector of Pakistan's economy, so country is dependent on crop production for not only ensuring its food security but also economic prosperity, which is manifested by the fact that the share of this sector in its GDP is 24% (Pakistan Bureau of Statistics, 2019). This study focuses on impact of drought on the crop production at the sub-national level of Pakistan.

Drought is defined by precipitation deficit in term of Standardized Precipitation Index (SPI) and the chosen time scale of index for this study is 6 months to cover an entire crop season. Impact of drought is studied at the seasonal level and individual crop level using a statistical model which includes the impact of SPI as a variable. Results from the analysis show that a strong correlation exists between the drought and Rabi crop production for Balochistan and KPK provinces, which have limited natural resources; whereas no such correlation exists for the provinces of Punjab and Sindh, since there is already an abundant presence of various natural resources in the form of extensive irrigation network, ground water and fertile plains with suitable temperature. This relationship between the drought and its impact on the wheat production is positive in those provinces.

The major crops of the Kharif season are rice, cotton, sugar cane and maize. The modeling analysis does not show any correlation between the drought and their respective production as these crops are mainly sown on rainfed crop land, while a small fraction of maize

is sown both on rainfed and irrigated cropland. The Kharif season has comparatively fewer dry periods than the Rabi season because of the Monsoon, and thus the crops in the Kharif season are less vulnerable to the droughts ranging from mild to moderate than the Rabi season crops.

ACKNOWLEDGEMENTS

To my advisor Professor Ximing Cai, who consistently guided me with patience during my M.S. His compassion and concern for his students is remarkable and I am grateful for the time and ideas which he gave me. Working in his group was an honor for me, which has an excellent working environment and a helping attitude.

To my parents for their unconditional love, constant support and encouragement to pursue my dreams. To my wife and children for their love, patience and support, which gave me courage to achieve my goals. To my friends and family who extended their moral support and my colleagues for their guidance, especially Tushar Apurv, who gave me his time and positive input during this study.

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CHAPTER 1: INTRODUCTION

Background

Expected world population by 2050 is 9.8 Bn (United Nations, 2017) and the global food demand will increase by 70 to 100% by 2050 (Godfray et al., 2010). Thus the world is facing a challenge in matching the increasing food demand while crop production has been affected by climate change. An average decadal rise in mean temperature of 0.13^{o} C is observed since 1950 and the same is expected to increase to 0.2^{0} C per decade in the coming two to three decades (Lobell et al., 2011). Climate change is not only causing increase in surface air temperature but also responsible for the increased frequency of extreme climatological events as the occurrences are more than doubled since 1980 (European Academies Science Advisory Council, 2018). Drought and extreme heat events significantly reduce crop production (Lesk et al., 2016) and that is why studying the climatic factors on crop production is important in order to identify solutions to ensure food security in the future.

Studying droughts and their impact on the agriculture sector is not only important to ensure food security but to enhance the economic prosperity of a country. Fifty years severe and prolong drought of Pakistan from 1998 to 2002 reduced the GDP growth of the country by 50 % (Ahmed, 2015), which is huge for a country with agrarian nature of economy.

Drought impact assessment on crop production is challenging because of the inherent complications within each phenomenon. Drought is determined by multiple factors and their interaction which includes precipitation, temperature, vapor pressure and solar radiation whereas production is affected by precipitation, temperature and the agronomics so resultantly production response to drought becomes complicated (Leng and Hall, 2019). In this thesis drought will mainly be defined by the spatial and temporal variation in precipitation only, using Standardized Precipitation Index (SPI), which is widely used as an effective drought index (Madadgar et al., 2017; Vicente-Serrano et al., 2012 & Shah et al., 2015) and also recommended drought index by World Meteorological Organization (WMO, 2012). Lesk, Rowhani & Ramankutty (2016) in "Influence of extreme weather disaster on global crop production" found that the extreme heat affects the yield of crop only, whereas drought affects the yield and the harvesting area both. Previous studies mostly consider the impact of drought on the crop yield only, ignoring its impact on the harvesting area. In this thesis an effort is made to see the impacts of drought on the crop production instead of the yield only, as change in the crop production includes yield effect, production effect and interaction effect (Rehman et al., 2011), and the same is shown in Equation (1.1) and that's why this brings in more complication to the model.

$$\Delta P = \underbrace{A_o*\Delta Y}_{\text{Yield effect}} + \underbrace{Y_o*\Delta A}_{\text{Area effect}} + \underbrace{\Delta A*\Delta Y}_{\text{Interaction effect}} \tag{1.1}$$

A_o	Area
Y_o	Yield
ΔA	Change in area
ΔY	Change in yield

Scope of Thesis

The region of Pakistan, which is considered for this study has an area of 79.6 million hectors out of which 21.2 million hectors is cultivated area, 20 % of total cultivated land is rainfed whereas 80 % of cultivated land is irrigated (FAO, n.d.). Study is carried out at the second tier of administrative echelon, which is known as province / territory, each province/ territory is further sub divided into divisions. Out of seven administrative units of Pakistan, four administrative units (provinces) which are mainly responsible for the cereal crop production will be considered for this study. The four provinces which are considered for this study are Balochistan, Khyber

Pakhtunkhwa (KPK), Punjab and Sindh only as shown in Figure 1.1. Punjab and Sindh provinces produces the largest portion of country agricultural production because of the availability of plain fertile lands, pumping of ground water in abundance without any check and balance and extensive irrigation system.

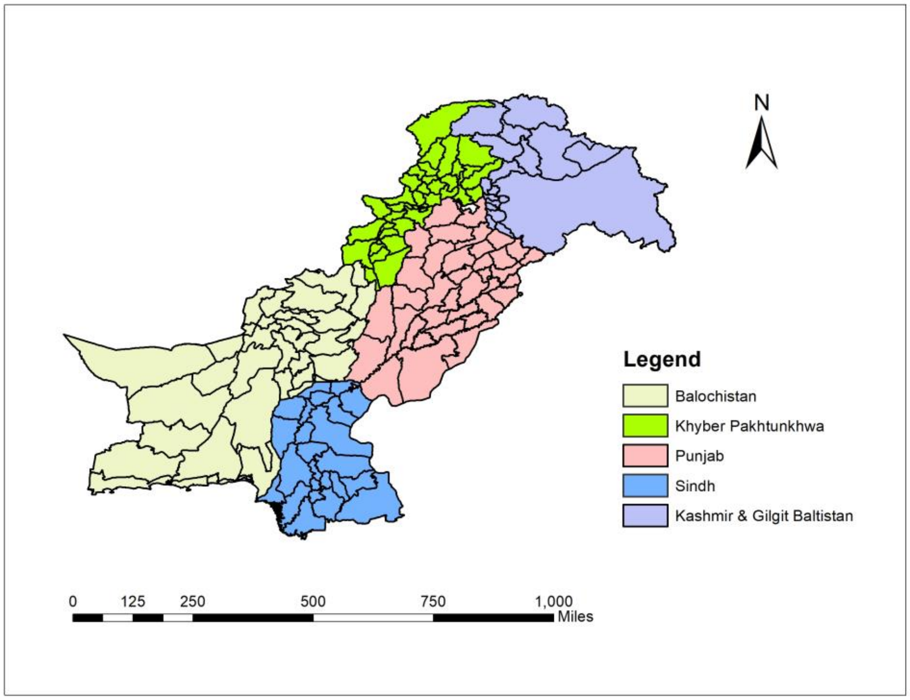


Figure 1.1 Tier two and three of Pakistan administrative units, subdivision within each province / territory.

Whereas share of Balochistan and Khyber Pakhtunkhwa in production of Pakistan agriculture is considerably less because of less plains, fertile land, ground water and irrigation water. In this study provinces will also be referred as western provinces including Balochistan & Khyber Pakhtunkhwa and eastern provinces including Punjab & Sindh for a comparison of drought impacts on the rainfed cropland and irrigated cropland. Land cover as shown in Figure 1.2 shows that eastern province has an extensive irrigation system which basically act as buffer against drought and western provinces mainly have rainfed cropland, which makes them very vulnerable to the drought.

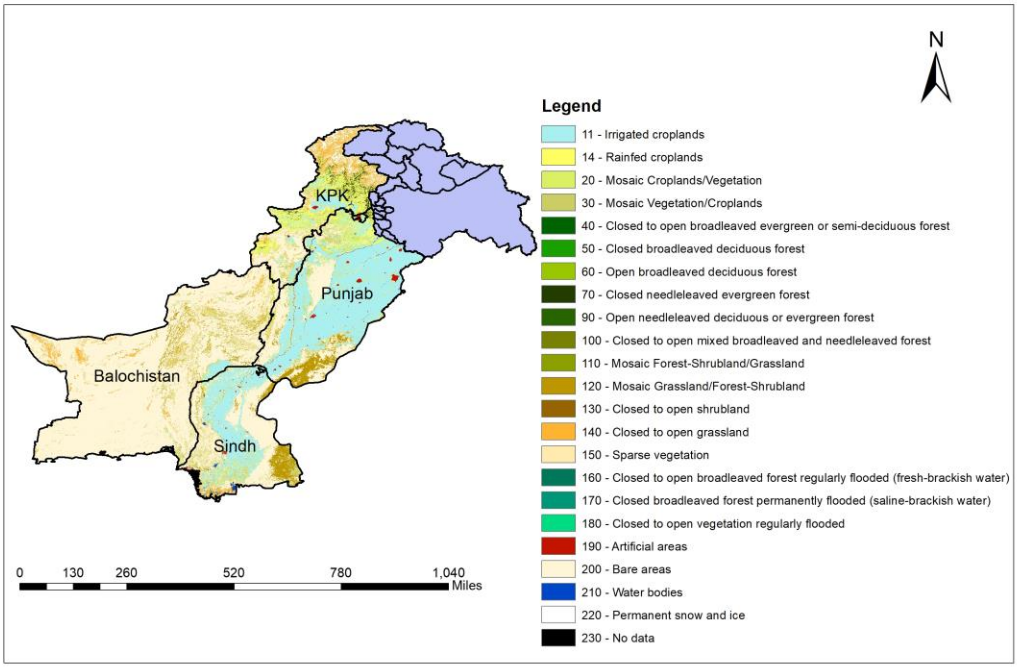


Figure 1.2 Land cover of Pakistan

Impact of drought on crop production is studied seasonally, as Pakistan has two principal seasons Rabi and Kharif. Rabi crop is also known as winter season crop, which includes wheat as a major crop and Kharif crop is also known as summer season crop, which includes rice, cotton, maize and sugarcane as the major crops. Drought will be defined in term of SPI index, which will be transformed to seasonal SPI and will be correlated to seasonal production. Production increases with time as a result of increase in the harvesting area and crop yield (improved agronomics & technology) but if there is a decrease in available water resources it will make crop production more vulnerable than ever. In this study the objective is to explore the impact of drought on crop production and how this impact varies spatially from rainfed dominant cropland to irrigated dominant cropland.

Research Questions

Would drought impact the crop production? Intuitively, it is a very simple question, yet the complications within the drought and crop production make it very difficult to answer. Mostly, the research which has been carried out so far considers the impact of climatic factors on yield of crops only. However, in this study impact is studied on the production of crop which includes impact on both yield and harvesting area. Studying impact of drought on crop production is very important especially for rainfed areas, where farmers may not even sow a crop based on their recent experience of drought or a forecast of drought. In Pakistan where there are no laws over the usage of ground water makes it even more complicated to answer this question.

How does this impact change from rainfed crops to irrigated crops? Vulnerability of different types of crops harvested on rainfed or irrigated cropland to drought will be studied to understand the resilience within different types of crops and the system. In rainfed system the main source of water is green water with some ground water support staring from germination through all phases of crop growth, which makes it more vulnerable to the drought, even the smaller shocks. In irrigated system the main source of water is blue water with additional support of green water and ground water, which makes it more resilient to external shocks. The same phenomenon will be studied for Pakistan irrigation systems.

How could the crop growth models used for expected crop production be improved by including drought? There are several growth models in existence to determine the growth rate and based on it determine the expected crop production, which mostly consider the time trend and capacity of the system. They successfully determine the growth rate based on existing data set, but the expected crop production can be improved by considering the drought factor in to account, if the crop production data set shows a correlation between itself and the historic droughts.

Would vulnerability of crop production increase with time? In a system the available resources and their consumption is constantly changing which makes it very difficult to assess the rate of change of vulnerability. In any system initially the quantity of resources to be used are high, which decreases with time and a deceleration in growth happens, so would the same phenomenon effect the vulnerability of the system. A sensitivity analysis will be carried out for the data sets which show an impact of drought on itself, to check the relationship between the vulnerability and time for a system.

Thesis Outline

Chapter 2 covers the drought part of analysis, in which different types of droughts and drought indices are defined. It basically tries to establish a reason for the selection of standardized precipitation index as the drought index used in this study and the time scale as 6 months for the seasonal analysis. At the end of this chapter the results of SPI are shown at provincial level and their transformed version, which is used for the analysis.

Chapter 3 covers the crop production of Pakistan seasonally, and the reasons for the selection of crops used for the study. It also covers the seasonal water footprint of the country at sub regional level, which is used for the seasonal analysis to determine a correlation between the drought and seasonal crop production. Conversion of crop production data to seasonal water footprint was significant in providing a baseline for the seasonal analysis.

Chapter 4 covers different correlation and growth models in use and their advantages and disadvantages. It also covers the usage of different models for different systems and why were they not suitable for the data set of Pakistan. A generalized nonlinear model was used for the analysis which gave a universal correlation between the production data sets and time trend at sub regional level of country. Drought defined in term of SPI was added to this proposed model as a linear function to check its significance.

Chapter 5 covers the impact of drought, which is defined and covered in chapter 2 on the seasonal crop production in term of water footprint and crop production data individually, which is discussed in chapter 3. Results are studied in detail and several deductions are discussed to understand the underlying causes and limitations.

Finally, Chapter 6 covers the conclusions and the description of future work.

CHAPTER 2: DROUGHT ANALYSIS

Types of Drought

According to NOAA (2019) drought is defined as "… *the absence of water. [Drought] is a creeping phenomenon that slowly sneaks up and impacts many sectors of the economy and operates on many different time scales*". Climatological community categorized drought in to four groups.

Meteorological drought is defined as the degree of dryness and its duration, which is defined by comparing present conditions with past normal or average conditions. This phenomenon is region specific as the same amount of precipitation at different locations may or may not indicate presence of drought.

Agricultural drought is a result of meteorological drought, a short-term meteorological drought may cause absence of soil moisture and reduction in evapotranspiration affecting crop yield and a long-term meteorological drought may affect ground water, streams water and reservoir affecting harvesting area in addition to the yield. So, agricultural drought occurs, when crops are affected.

Hydrological drought is also linked with meteorological drought and happens when water reduction in streams and reservoir is observed. Meteorological drought could be short term whereas hydrological drought takes time to develop and recover back.

Socioeconomic drought may or may not be caused by meteorological, agricultural and hydrological drought. It occurs when demand of an economic good exceeds its supply like grain, fish, hydropower and water. This shortage between demand and supply could be caused by above mentioned droughts or an increase in the population and improved living standards.

Drought Indices

Several drought indices have been developed and used to define the drought, its duration and intensity. Some prominent and commonly used drought indices will be discussed below.

Palmer drought severity index (PDSI) was defined by palmer in 1965, according to him this analysis which was later named as Palmer index or palmer drought severity index is a mean of describing and measuring drought (Palmer, 1965)

Standardized precipitation index (SPI) is defined in “The relationship of drought frequency and duration of time scales” (McKee et al., 1993) as an indicator which needs only one input variable to define drought and the same can be used to monitor drought. Precipitation data is normalized with a probability distribution function such that SPI values are the standard deviations from the median (WMO, 2012).

Standardized precipitation evapotranspiration index (SPEI) was proposed in “Standardized precipitation evapotranspiration index revisited: parameter fitting, evapotranspiration models, tools, datasets and drought monitoring” (Vicente-Serrano et al., 2010), which is an extension of SPI as it includes temperature data in addition to precipitation to see a the effect of global warming on drought.

SPI/ SPEI correlation with PDSI improves from 1 to 12-month time scale and decreases afterwards, showing 12-month PDSI is strongly correlated with SPI/ SPEI. Impact of drought on yield is studied for different indices and SPI/ SPEI indices show a stronger correlation with the yield than the PDSI yield correlation (Liu et al., 2018). As in our analysis we have considered a 6-month time scale to cover an entire season to analyze agricultural drought, SPI / SPEI become more reliable indicators of drought.

Irrespective of the system (hydrological, ecological or agricultural) analyzed, SPI/ SPEI show a strong correlation with different variables causing temporal variability than the PDSI and in term of magnitude the correlation of SPI/ SPEI with the response variables of different systems range from 70% to 95%, whereas PDSI showed less than 15% of highest correlations (Vicente-Serrano et al., 2012).

SPI/ SPEI are better drought indicators than PDSI and comparing SPI with SPEI there may exists little differences between the two in terms of capturing temporal variability and hence SPI would naturally become a better choice because of the lesser data requirement (Vicente-Serrano et al., 2012). In this analysis SPI was selected as drought indicator because of its simplicity in terms of data requirement and yet effectiveness in term of reliable results.

Standardized Precipitation Index

Standardized precipitation index user guide (WMO, 2012) and "The Relationship of Drought Frequency and Duration of Time Scales" by McKee et al., (1993) were referred to describe methodology to calculate SPI. SPI can be calculated for different time scales (1, 3, 6, 9, 12, 18, and 24 months, etc.), which uses the aggregate of monthly precipitation for that many months, so a 3 month SPI for the month of December for a particular year will be a comparison of the accumulated monthly precipitation for the months of October, November and December for that particular year to the precipitation total of October, November and December of all the years of data set (WMO, 2012). Different time scale SPI have different utilization and can be used to see impact of different types of droughts, starting with the impact on soil moisture to the impact on water channel and reservoirs. If the time scale is less than 1 month and more than 24 months, SPI results may become unreliable. To achieve reliable results a minimum of continuous 30 years data of monthly precipitation should be used in the analysis (WMO, 2012).

As already mentioned for better results of SPI, long term precipitation data sets are used, and the first step is aggregating of precipitation data set for a location at a desired time scale. Then the same aggregated data set is fitted to a probability density function. Next step is to use the function to calculate the cumulative distribution function followed by its transformation into normal distribution so that the mean SPI is zero (WMO, 2012). A Positive value of SPI means a wetter period as it indicates more than median precipitation and the negative value of SPI means a dryer period as it indicates less than median precipitation, according to SPI a drought period begins when SPI value less than or equals to -1.0 (WMO, 2012). Drought has been categorized based on the range of SPI (McKee et al., 1993) as shown in table 2.1.

Table 2.1 Categories of drought as per SPI

Drought Categories	**SPI Values**
Mild drought	0 to -0.99
Moderate drought	-1.0 to -1.49
Severe drought	-1.49 to -1.99
Extreme drought	-2.0 to -3

Data Sources

Global precipitation data was obtained from the Centre for Environmental Data Analysis (CEDA) Archive and the specific data set used was “CRU TS 3.23: Climatic Research Unit (CRU) Time-Series (TS) Version 3.23 of High-Resolution Gridded Data of Month-by-month Variation in Climate (Jan. 1901- Dec. 2014)”. The data set is a time series gridded data (0.5x0.5 degree) at a monthly time scale for a period from January 1901 to December 2014, produced by the CRU at the University of East Anglia (University of East Anglia Climatic Research Unit, Harris & Jones, 2015). Gridded precipitation data of Pakistan was extracted from the global data set, which was subsequently used for calculation of SPI for Pakistan at 0.5x0.5 degree.

Results

Time scale for this analysis was considered as 6 months, the reason was to find a correlation at seasonal level with the crop production which may take from 4 to 6 months. Rabi season crops are generally harvested from month of April to May and that is why 6-month SPI for the month of April is determined to carry out the analysis and determine any possible correlation between the drought and Rabi season. 6-month SPI for the month of April includes the impact of precipitation of past six months including the month of April, which covers the entire season. Kharif season crops are generally harvested during the month of October to December, so 6-month SPI for the month of October is determined to carry out the analysis and determine any possible correlation between the drought and Kharif season. Sugar cane is generally harvested in the month of December, less sugar cane 6-month SPI for the month of October which includes the impact of precipitation of past six months including the month of October covers all the seasonal crops.

First step was to determine SPI from the global data set for the available period of 1901 to 2014 at monthly time scale. SPI was calculated using SPI Code in MATLAB and results were generated at 0.5x0.5 degree grid for Pakistan along the time series. The results provide an insight to the temporal and spatial variation of the drought. SPI of all the grids within each province would be averaged out to give a representative SPI and the same would be used for the analysis, results are available in Appendix A. All the results showing spatial variation for the entire period (1901 to 2014) cannot be shown, however results of Pakistan fifty years worst drought period from 1998 to 2002 (Spinoni et al., 2019) showing spatial variation are shown in Figure 2.1. Even within provinces there is a lot of spatial variation which is averaged out for the representative SPI and the correlation may not be very accurate. Availability of SPI results at 0.5x0.5 degree grid makes it very flexible to generate SPI at any administrative level even at district level but the limiting factor for analysis is availability of crop production data, which is available at provincial level.

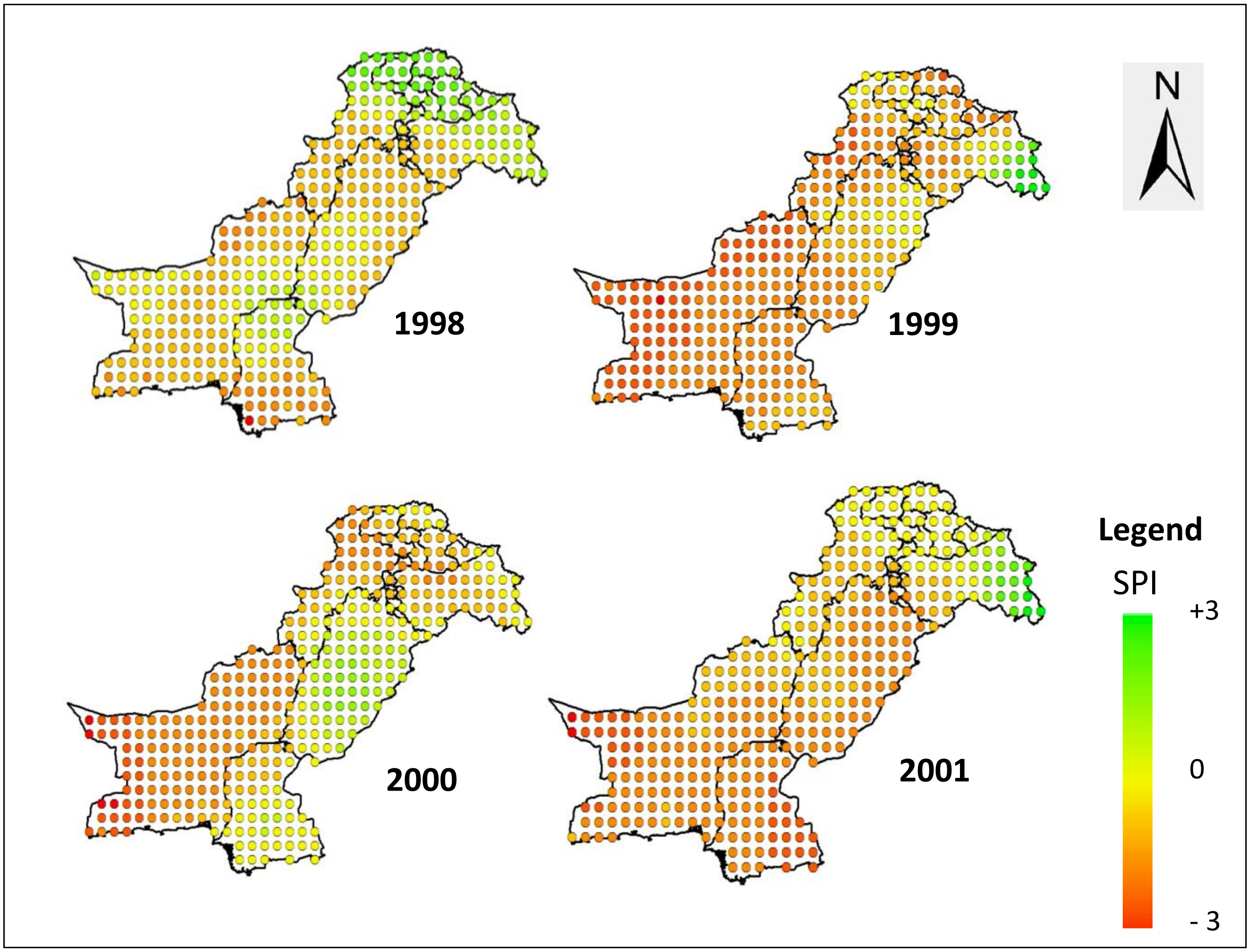


Figure 2.1 Spatial variation at provincial level for 50 years worst drought period

The temporal variation of 6 month average SPI for Balochistan, KPK, Sindh and Punjab are shown Figure 2.2 (a), Figure 2.3 (a), Figure 2.4 (a) and Figure 2.5 (a) respectively, which is at monthly time step. Next step was to transform this average SPI at monthly time scale to seasonal SPI at annual time scale by selecting the April SPI of the complete period for Rabi season and October SPI of the complete period for Kharif season. This transformation was important because the analysis must be carried out at the same time step, which is annual. The transformed seasonal 6-month SPIs are shown in Figure 2.2 (b), Figure 2.3 (b), Figure 2.4 (b) and Figure 2.5 (b) for Rabi season and in Figure 2.2 (c), Figure 2.3 (c), Figure 2.4 (c) and Figure 2.5 (c) for Kharif season of all provinces

6-month SPI at annual time scale is further reduced to a period from 1971 to 2014 for the analysis, the reason for selecting this period is discussed in chapter 3. Sindh province and Balochistan province have a semi-arid to arid climate, which can be observed from comparing the results of Balochistan and Sindh drier periods with KPK and Punjab drier periods and former set is more prone to droughts.

At sub national level, 6-month SPI for Rabi season shows dry periods of higher intensity and duration with comparison to the 6-month SPI for kharif season. Fifty years worst drought of the country spanning from 1998 to 2002 is more prominent in Rabi season than the Kharif season for all the provinces, so generally Rabi season crops are more vulnerable to the drought than the Kharif season crops. Kharif season has comparatively more wet periods than its dry periods because of the monsoon rains, except for the semi-arid Balochistan, which is facing a consistent dry period for the last one and half decade.

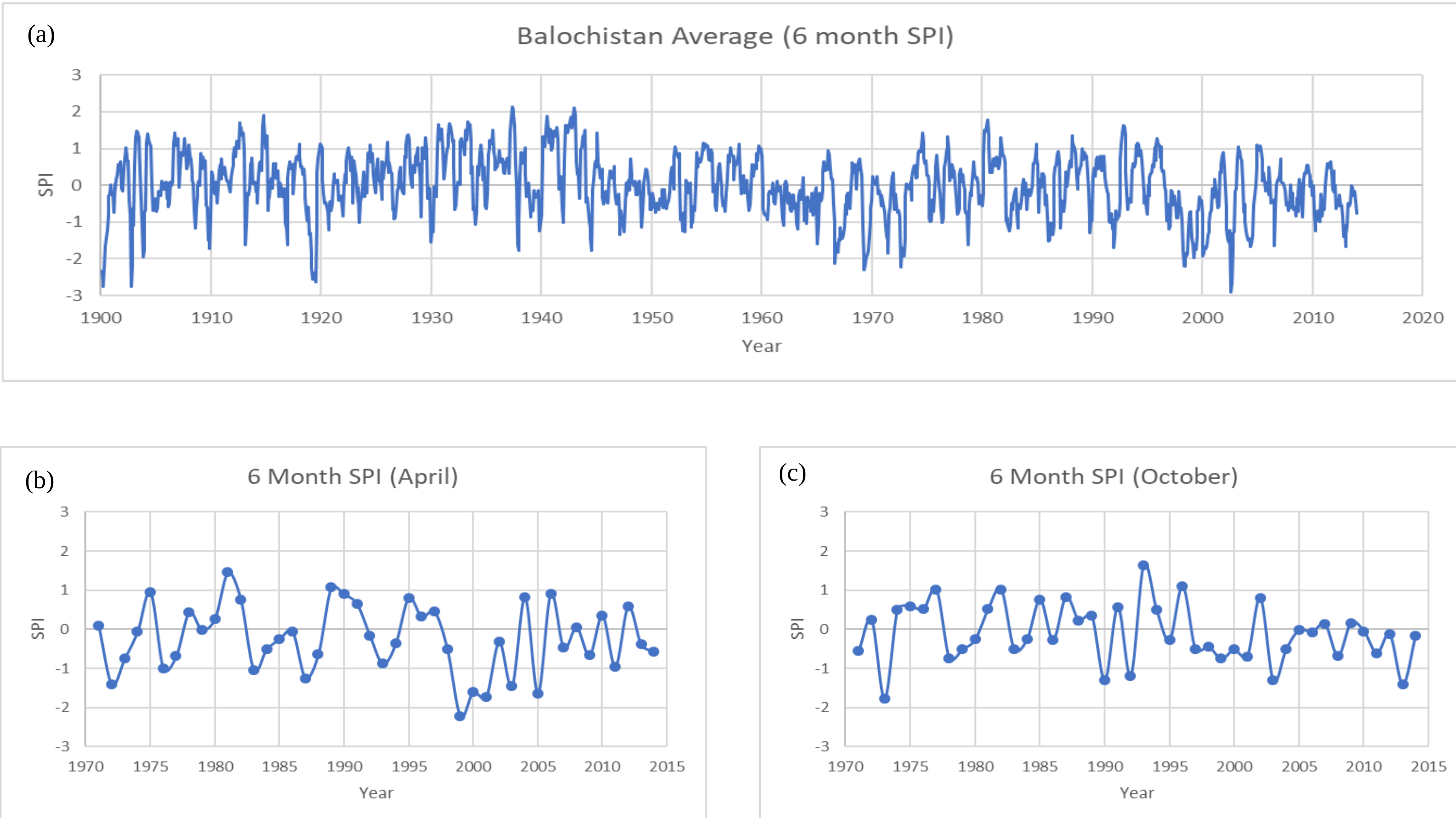


Figure 2.2 (a) SPI results generated at monthly timestep from 1901 to 2014 for Balochistan Province; (b) SPI results for Rabbi season at annual time step from 1971 to 2014; (c) SPI results for Kharif season at annual time step from 1971 to 2014.

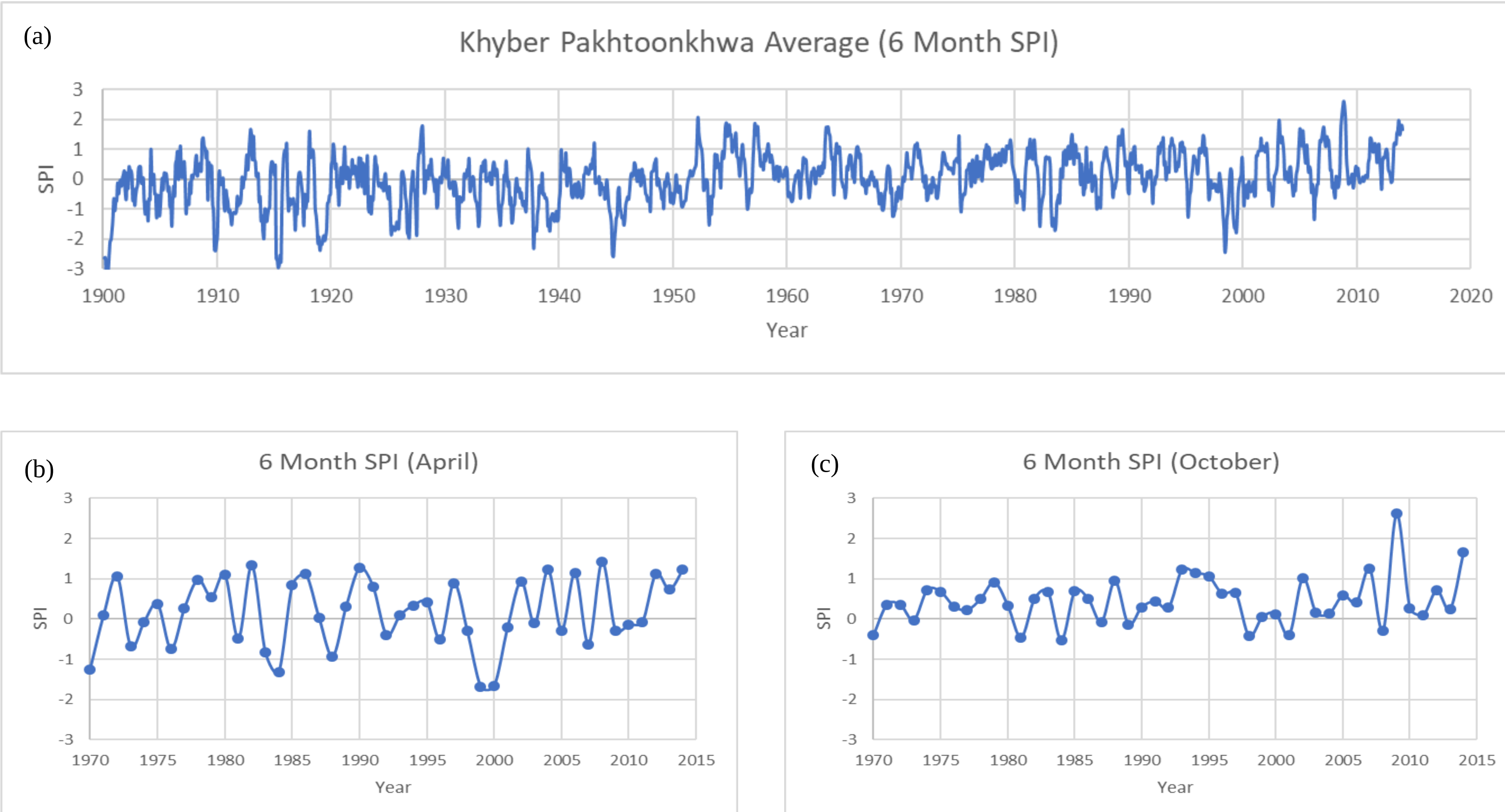


Figure 2.3 (a) SPI results generated at monthly timestep from 1901 to 2014 for Khyber Pakhtunkhwa Province; (b) SPI results for Rabbi season at annual time step from 1971 to 2014; (c) SPI results for Kharif season at annual time step from 1971 to 2014.

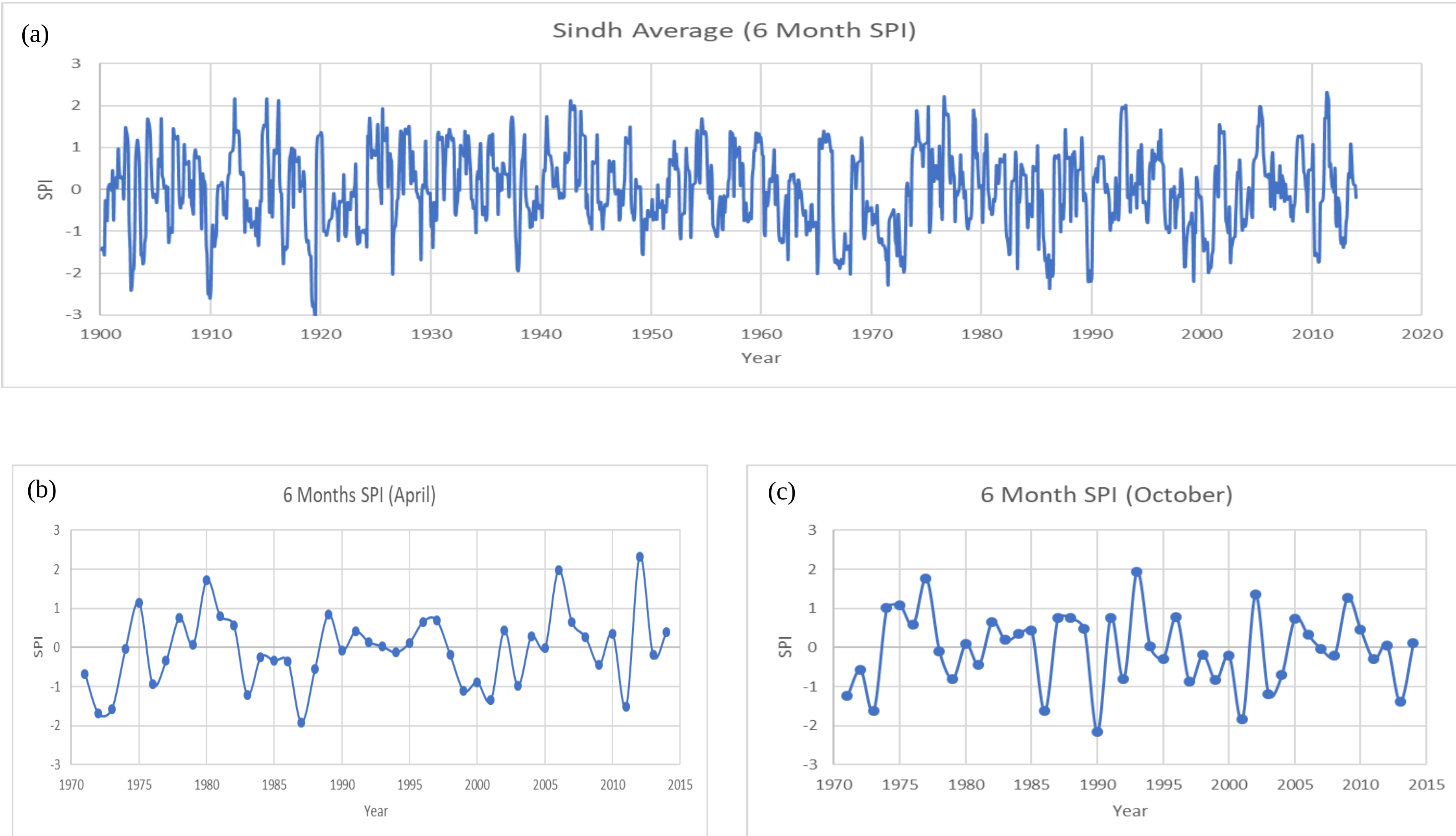


Figure 2.4 (a) SPI results generated at monthly timestep from 1901 to 2014 for Sindh; (b) SPI results for Rabbi season at annual time step from 1971 to 2014; (c) SPI results for Kharif season at annual time step from 1971 to 2014.

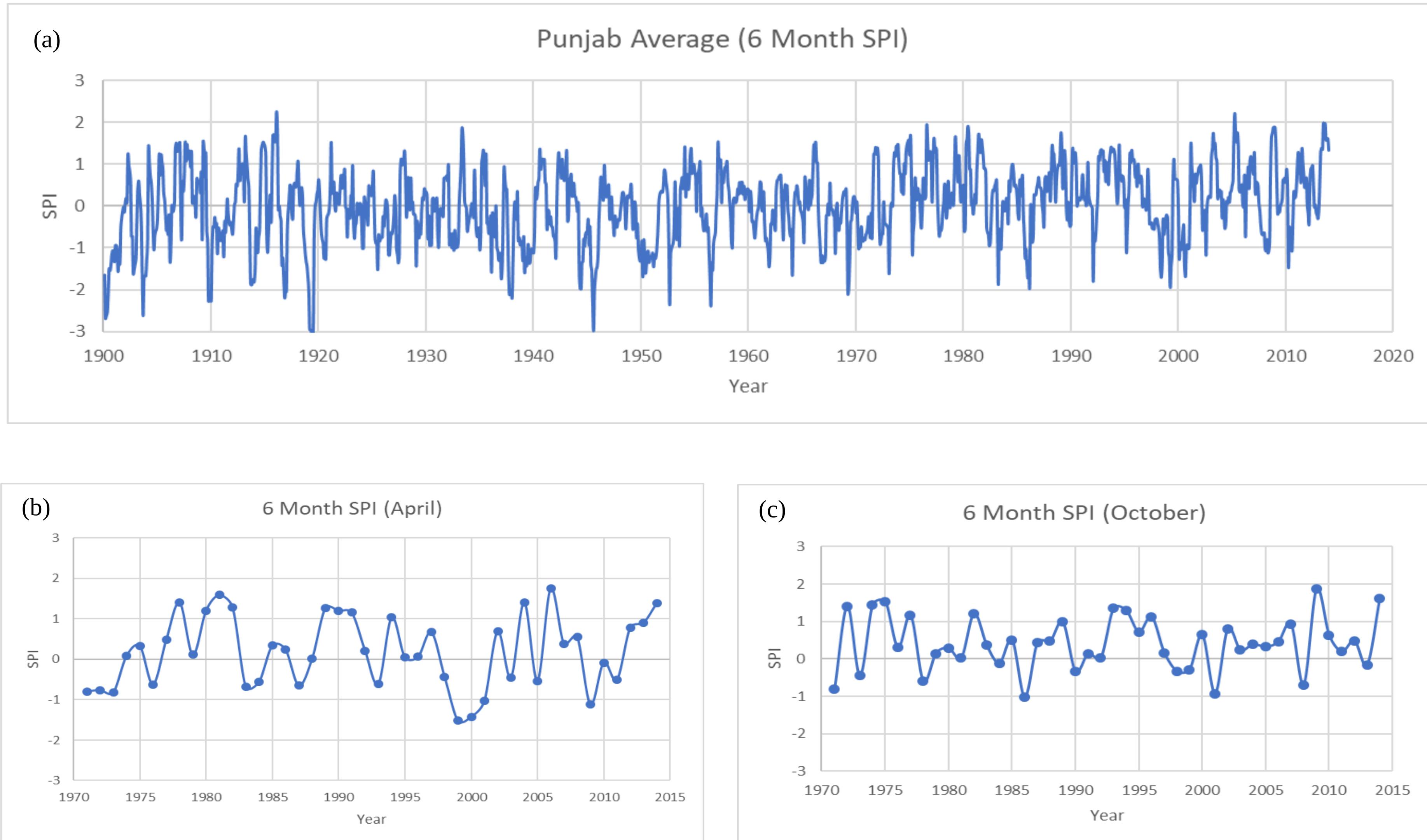


Figure 2.5 (a) SPI results generated at monthly timestep from 1901 to 2014 for Punjab; (b) SPI results for Rabbi season at annual time step from 1971 to 2014; (c) SPI results for Kharif season at annual time step from 1971 to 2014.

CHAPTER 3: AGRICULTURAL PRODUCTION

Principal Seasons

There are two main principal cropping seasons in Pakistan, Rabi and Kharif. Rabi season, which is a winter season, crops are sown in October / December and harvested in April / May. Rabi season crops are wheat, barely, tobacco, lintel and mustard. Kharif season, which is a summer season, crops are sown in April / June and harvested in October / December. Kharif season crops are Rice, moong, sugarcane, jowar, cotton, bajra and maize (Ministry of Finance Pakistan, 2018).

Impact of drought will be observed in both principal seasons. In order to simplify the problem only major crops will be considered and initially impact of drought will be studied at seasonal level by converting the crop production of all seasonal crops into the total water footprint at provincial level and subsequently impact will be studied on individual crops.

Major Crops and their Significance

Agricultural sector of Pakistan is very vital as it constitutes largest sector of economy. It contributes 24% to the country GDP and provides employment to half of the labor force of country (AMIS, 2017). The major crops of Pakistan by area harvested are wheat, rice, cotton, maize and sugar cane, which takes a share of 80 % of the total area harvested of all the crops including fruits and vegetables. Among these major crops, wheat harvested area takes a major share of 43.3 % followed by others (FAO, 2016) as shown in Figure 3.1. These major crops account 25.6 % in the value addition of agriculture sector and 5.3 % in GDP (Ahmad, Chani & Humayon, 2017). These major crops will be considered for the analysis, so for Rabi season only wheat will be considered and for kharif season only Rice, sugar cane, cotton and maize will be considered.

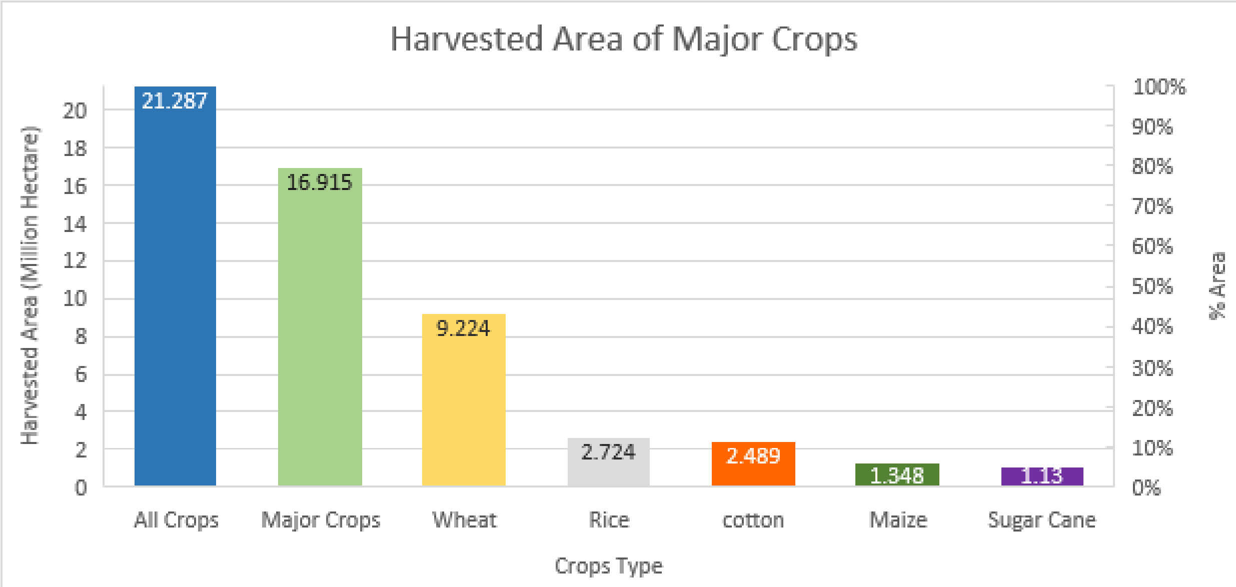


Figure 3.1 Share of major crops by area.

Provincial Share of Major Crops

World largest irrigation system is in Pakistan, which is fed by Indus river. Additionally, beneath the Indus river basin, country is blessed with an unconfined aquifer with a surface area of 16 Mha out of which 6 Mha is fresh water. So, during drought shortages in surface water is met by exploitation of ground water (Qureshi, 2011). In addition to the resources available in the country, green revolution in mid-60's played a vital role in improving growth rates of various crops especially wheat, which showed a tremendous increase. Another historical event which influenced the growth rates of the various crops was Structural adjustment program (SAP), which began in 1988 with the help of IMF and World Bank. Growth rate performance of all the major crop less rice have declined post structural adjustment period with comparison to pre adjustment period because of subsidy reduction on agriculture as one of the conditions of the agreement (Rehman, Saeed and Salam, 2011).

Eastern two provinces with suitable plains, availability of ground water and an extensive irrigation network cater for the largest portion of crop production. Share of major crops production of all the provinces for year 2016-17 is shown in Figure 3.2 (AMIS, 2017). Harvested area of major crops for all the provinces for year 2016-17 is shown in figure 3.3 (AMIS, 2017).

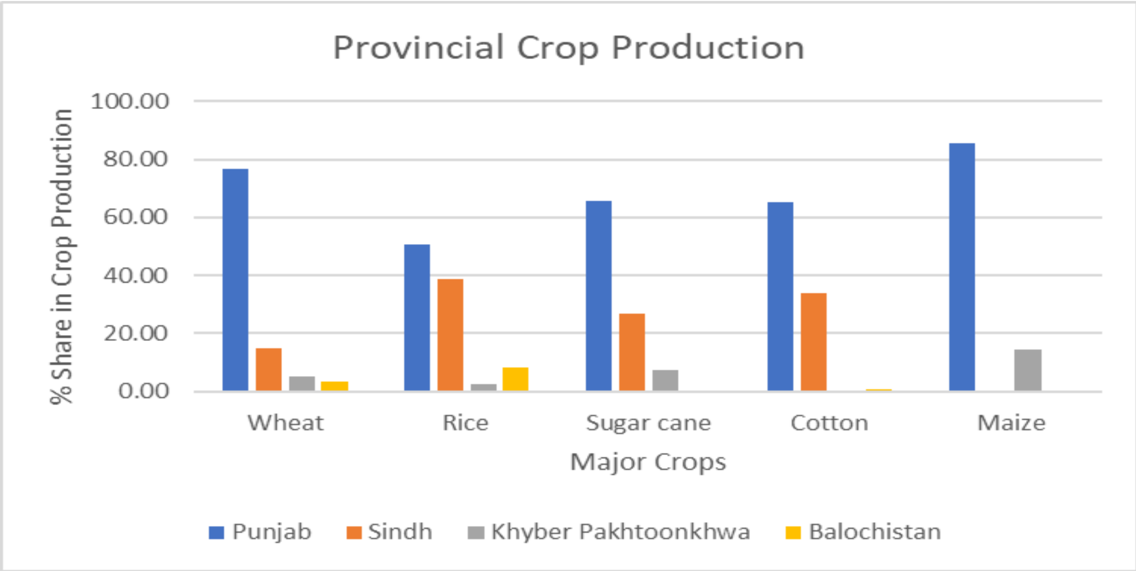


Figure 3.2 Share of major crops of provinces by weight.

Total harvested area of the major crops for eastern provinces from AMIS results shown in Figure 3.3 is 88 % approximately, which is responsible for producing the bulk of country crop production (AMIS, 2017).

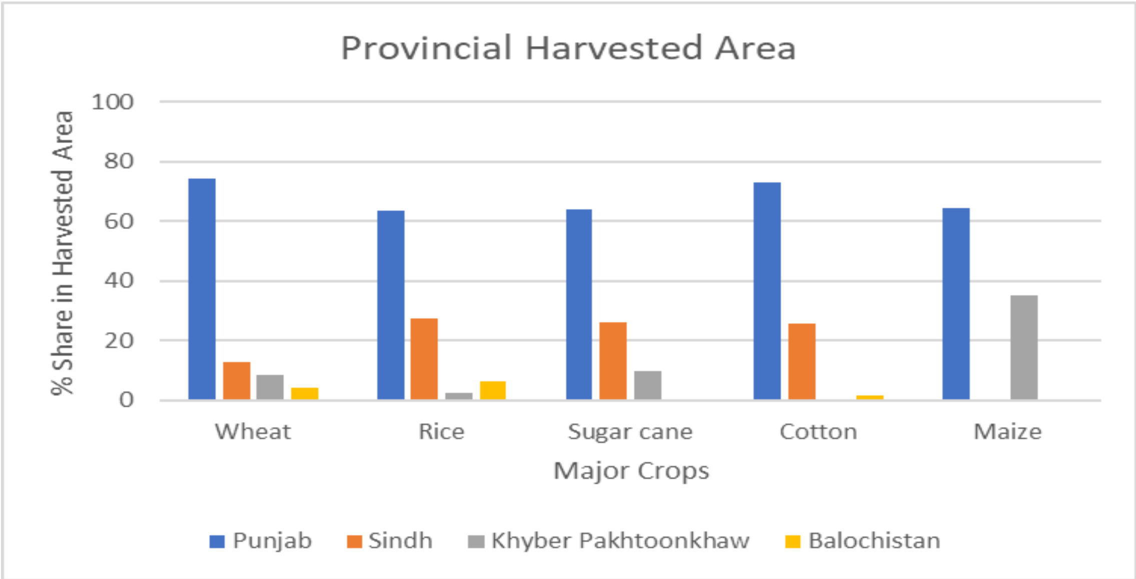


Figure 3.3 Share of major crops of provinces by harvested area.

Rainfed and Irrigated Crops

Rice, sugar cane and cotton are mainly harvested on irrigated crop land, whereas wheat and maize are harvested on both irrigated and rainfed crop land. No reliable data could be found for the maize production share from the irrigated and rainfed crop land at sub national level. Share of wheat production / area among the irrigated and rainfed cropland was obtained from Ministry of National Food Security and Research (NFS&R) for 16 years only and is attached in Appendix B.

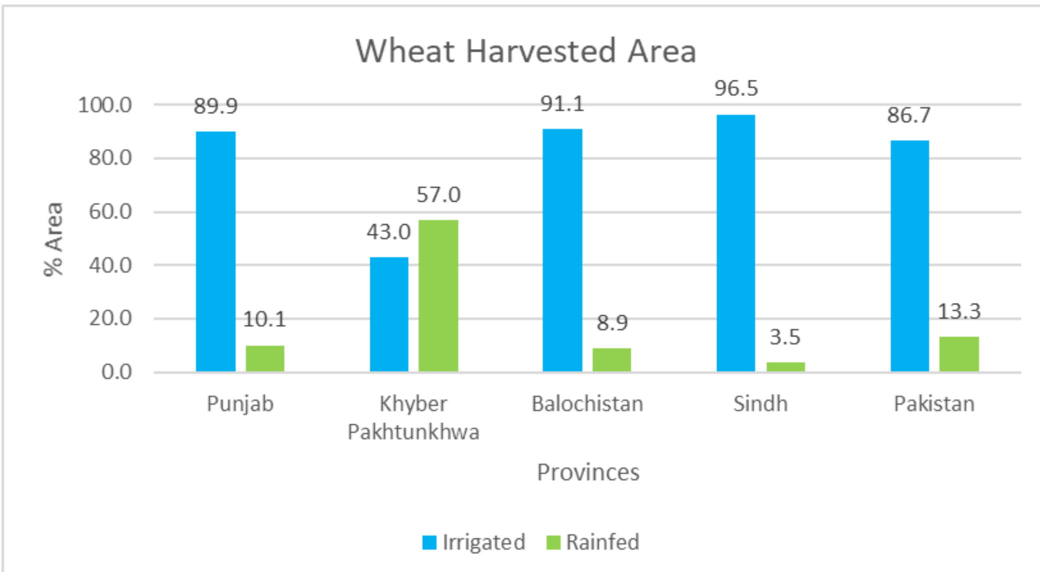


Figure 3.4 Wheat harvested area from irrigated and rainfed cropland.

Sixteen years available record is not enough to observe a direct correlation between the drought and production of wheat, however the same is averaged out to find a share of irrigated and rainfed wheat production and harvested areas within each province and the results are shown in Figure 3.4 for harvested area distribution and Figure 3.5 for wheat production distribution within all provinces. The same information will be used to deduce some important conclusions from the study. Share of irrigated cropland is 86.7% and rainfed cropland is 13.3% out of total wheat harvested area of Pakistan. At sub national level, except Khyber pakhtunkhwa, which has a 57 % of rainfed harvested area, rest all the provinces have predominantly irrigated cropland with a share of 90 % or more.

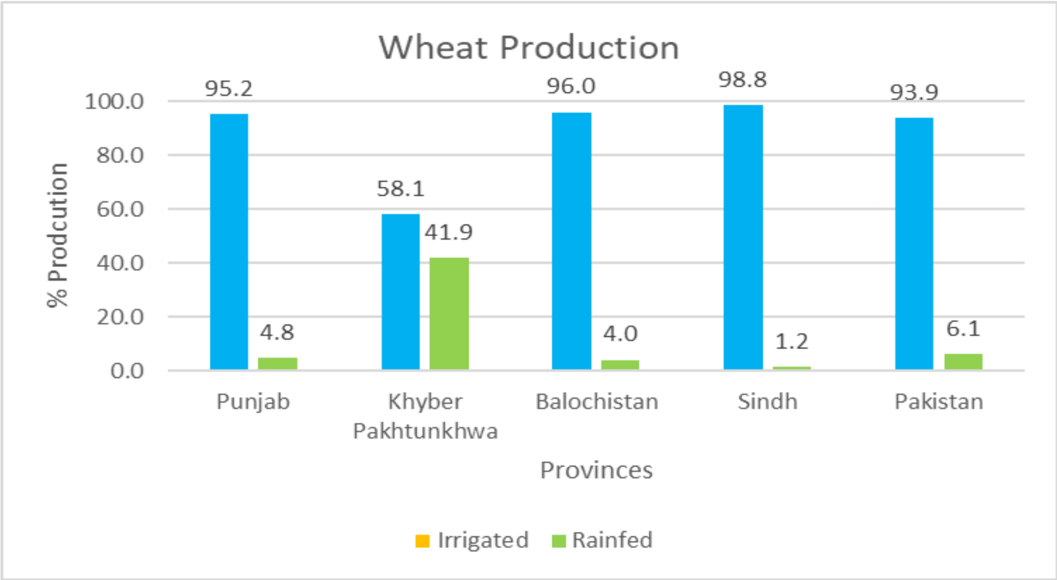


Figure 3.5 Wheat production from irrigated and rainfed cropland.

Water Footprint

In this study an effort is made to see the impact of drought at seasonal level to see a collective impact on all the crops in a specific season followed by impact on crops individually. Rabi season is the simplest with one major crop considered for the analysis so the impact of drought at seasonal level and at individual crop will be the same. Kharif season brings in complexity with consideration of four crops collectively, so at seasonal level production of all seasonal crops was transformed to the water footprint. Water footprint will be used as a representative of seasonal crops production for the analysis at seasonal level and crop production data will used directly for the analysis of individual crop.

Total water footprint of a season can be calculated using the production data and water footprint of all crops, same is shown in equation below.

$$\text{Total water footprint} = \sum (\text{Water footprint x Crop production})$$

Data Sources

Crop Production

Data for crop production is obtained from multiple sources, which includes Pakistan Bureau of Statistics, Agriculture Marketing Information Service (AMIS) Punjab and Ministry of National Food Security and Research (NFS&R) websites. Data was available for 32 crops from 1948 to 2014 but obtained for the major crops and a duration of 44 years from 1971 to 2014. Green revolution in mid 60s caused steep growth rate but the same couldn't be maintained for long and SAP in 1988 changed that growth rates again. Dataset had missing data in the initial period and the crop production is very low till 60s. So, in order to achieve better correlation, the initial period with missing data sets or very low crop production was ignored and the remaining period with a duration of 44 years covering the major events and increased crop production was used for the analysis.

Water Footprint

Data for water footprint of major crops and at subnational level was obtained from water footprint network website based on work in "The green, blue and grey water footprint of crops and derived crop products" by Mekonnen & Hoekstra (2011). Water footprint of all the crops at provincial level of the country are given in Appendix C.

Results

Total water footprint of Rabi season and Kharif season were calculated, and the results at provincial level are shown in Figure 3.6 and Figure 3.7 respectively. Reason of converting the crop production to its water footprint was to carry out analysis at the seasonal level and impact of drought on total water footprint will have a direct correlation with the its impact on the total crop production. Although for Rabi season, only one major crop (wheat) is considered and from analysis point of view it would not matter to carry out analysis at seasonal level with water footprint and analysis with the individual crop production as results would be the same, but for the comparison of results within seasons and within crops, both analysis were carried out.

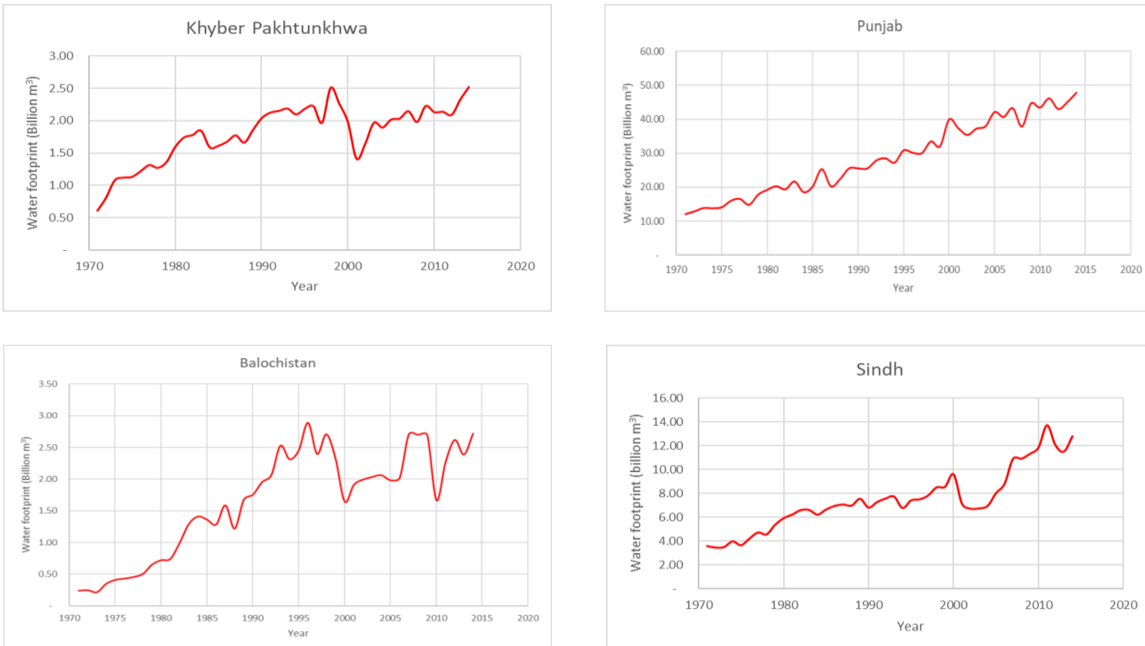


Figure 3.6 Rabi season water footprint at sub national level.

The temporal variation in water footprint is more evident in Balochistan, Khyber Pakhtunkhwa and Sindh province for both the seasons as shown in Figure 3.6 and Figure 3.7 with comparison to Punjab province which shows a stable and consistent growth. Punjab seasonal production is stable and less vulnerable to the drought because of the natural resources available to this province in term of extensive irrigation network, ground water and fertile plains. Other important reason for its stability is its share in the country total harvesting area, which is more than twice the collective harvesting area of remaining provinces, as per 2014 AMIS data harvesting area share of Punjab province for Rabi season major crops is 75.8 % and for Kharif season major crops is 69.3 % (AMIS, 2014).   So, if some specific districts of Punjab are even affected by drought, its effect would not be very evident in the Punjab province total production. Remaining provinces are limited by natural resources and harvesting area which makes them vulnerable to the drought and the variation in their production is a direct result of drought and policy changes.

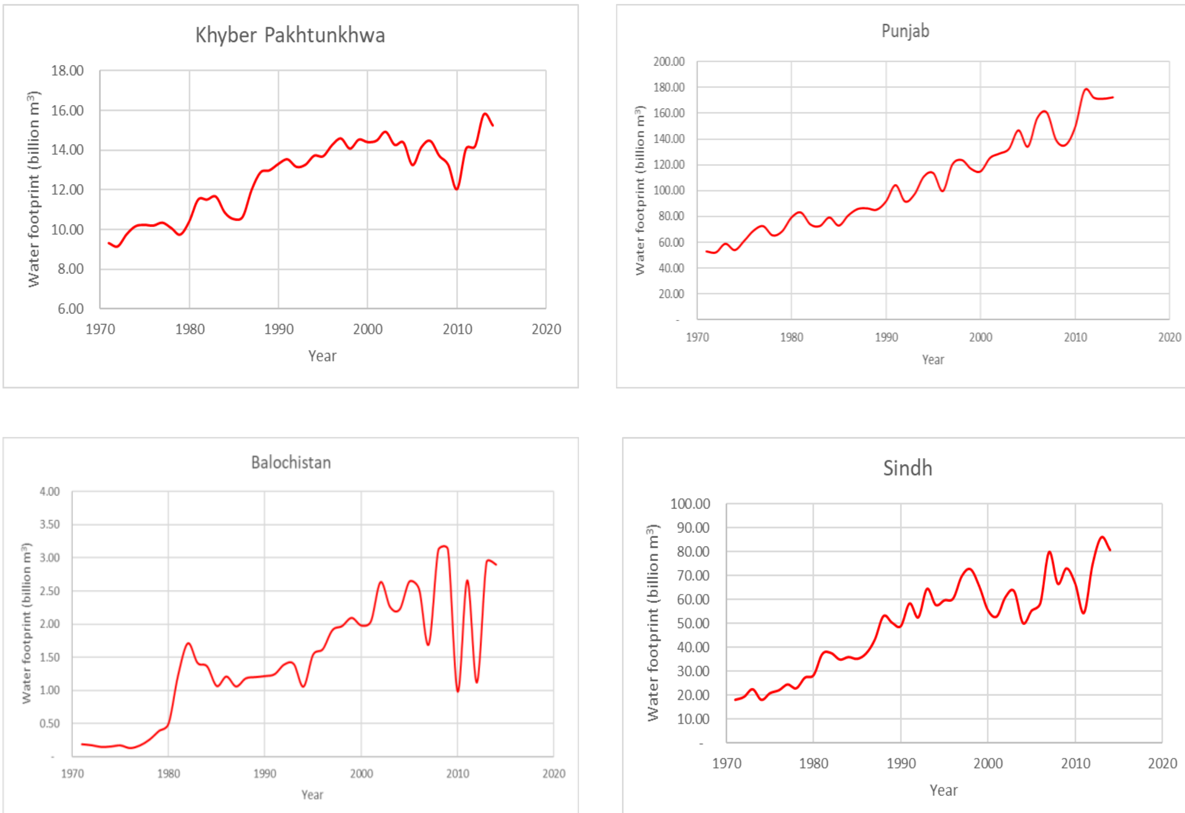


Figure 3.7 Kharif season water footprint at sub national level.

Punjab province produces 76.85 % of the total production of wheat and yet it shows a gradual increase over time with minor variations, whereas rest of the provinces shows abrupt changes in its growth over time trend as shown in Figure 3.8 (AMIS, 2014). Impact of Pakistan fifty years worst drought on wheat production of provinces is evident from 1998 to 2002 less Punjab. Although all the provinces less KPK are mainly dependent on irrigation cropland for Rabi season but even the surface water of Sindh and Balochistan couldn’t provide a buffer to the prolonged drought. Punjab province survived this drought by its reliance on ground water extensive use (auth). Highlighting these facts give some insight on the complexities of a system based on source of water use only.

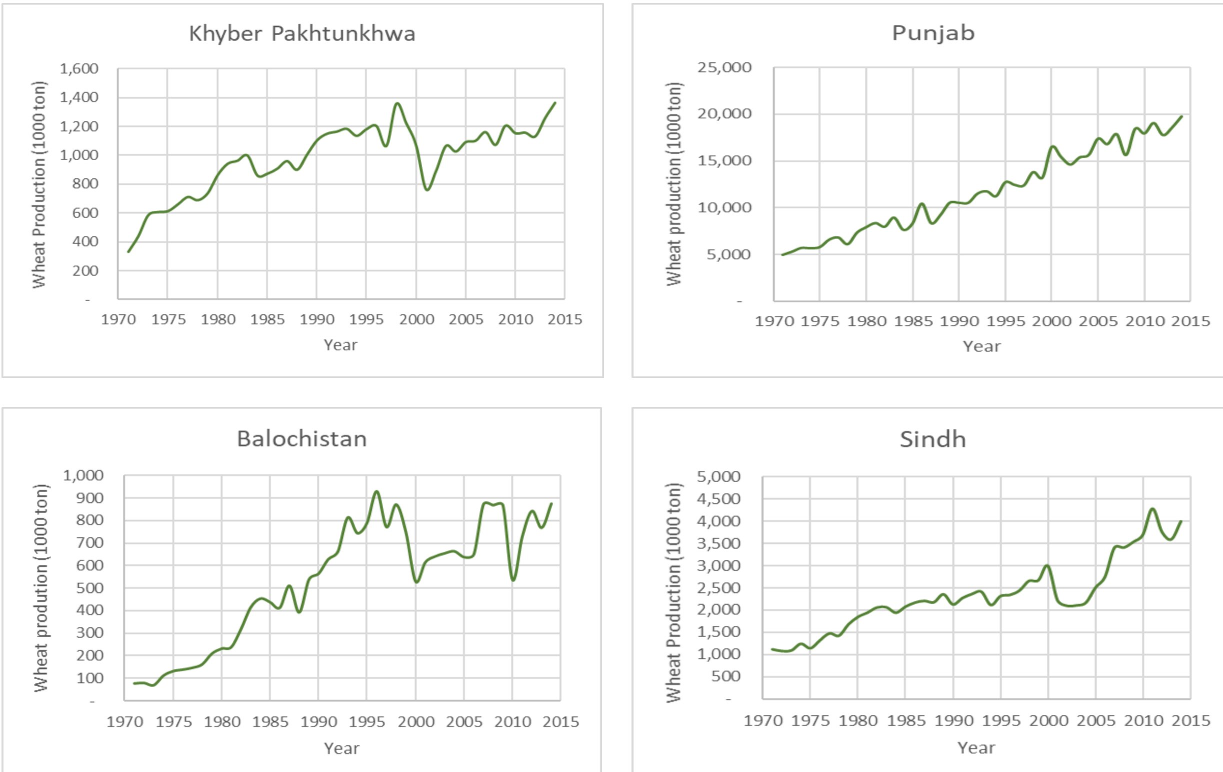


Figure 3.8 Provincial wheat production

As per 2014 data share of Punjab in sugar cane production is 65.37 % and rest of the sugar cane is produced by KPK and Sindh, whereas Balochistan share is negligible in this crop (AMIS, 2014). Cotton is the largest cash crop of Pakistan which is mainly produced by Punjab with a share of 73.6 % and Sindh with a share of 25.6 %, whereas KPK and Balochistan shares are negligible (AMIS, 2014). Rice is the second-best cash crop of the country, Punjab produced 52 %, Sindh produced 37.8 % and KPK and Balochistan produced around 10 % in 2014 (AMIS, 2014). Rice is again a water extensive crop and sown in irrigated cropland only. Main producers of maize are Punjab and KPK, which is sown on both rainfed and irrigated cropland. Almost all the crops less maize in Kharif season are irrigated crops, which makes them resilient to the mild droughts.

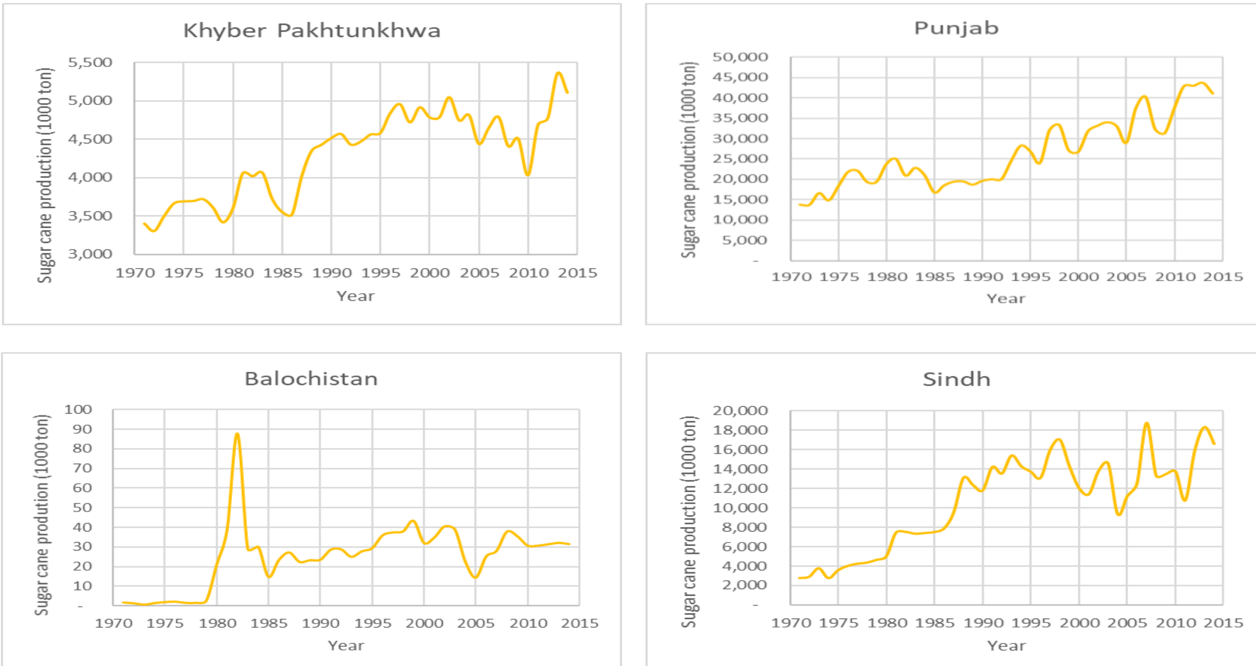


Figure 3.9 Provincial Sugar cane production

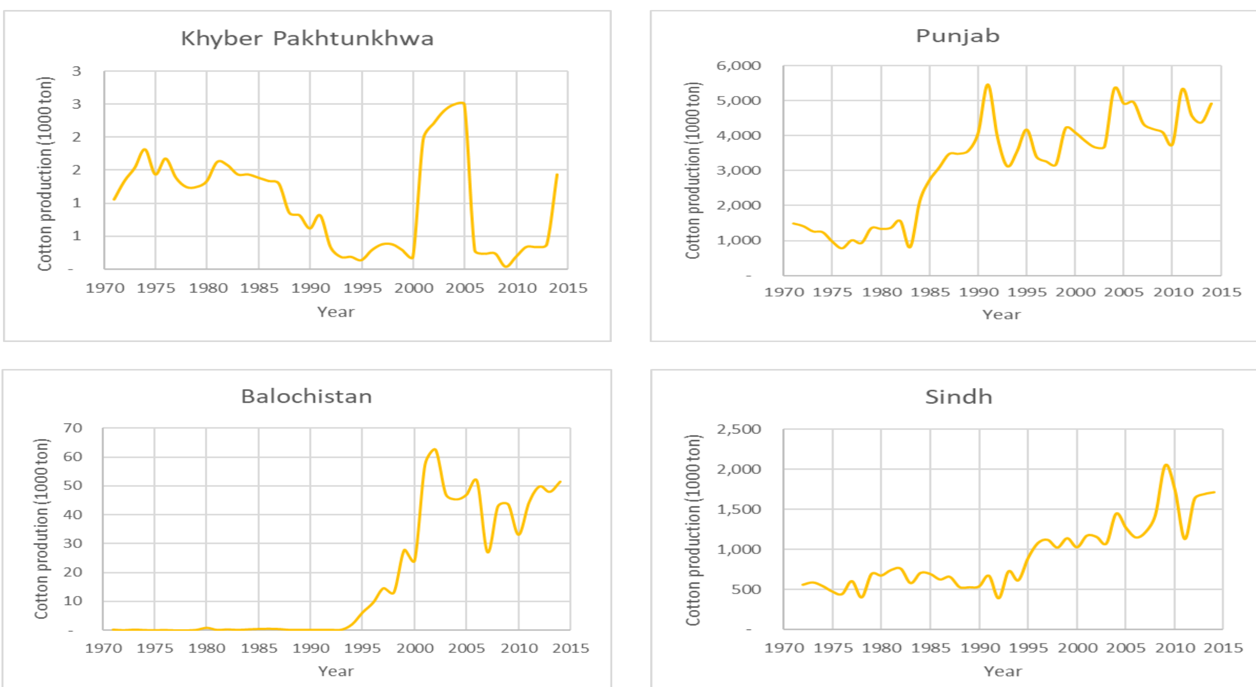


Figure 3.10 Provincial cotton production

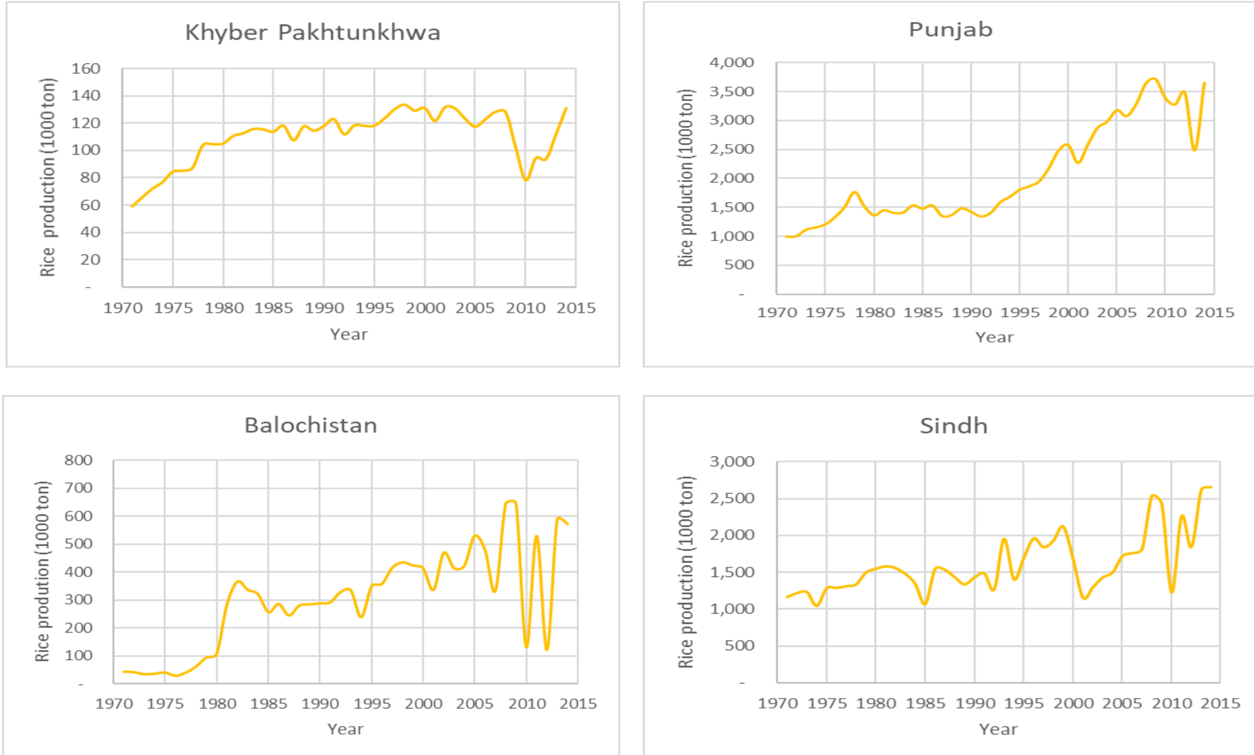


Figure 3.11 Provincial Rice production

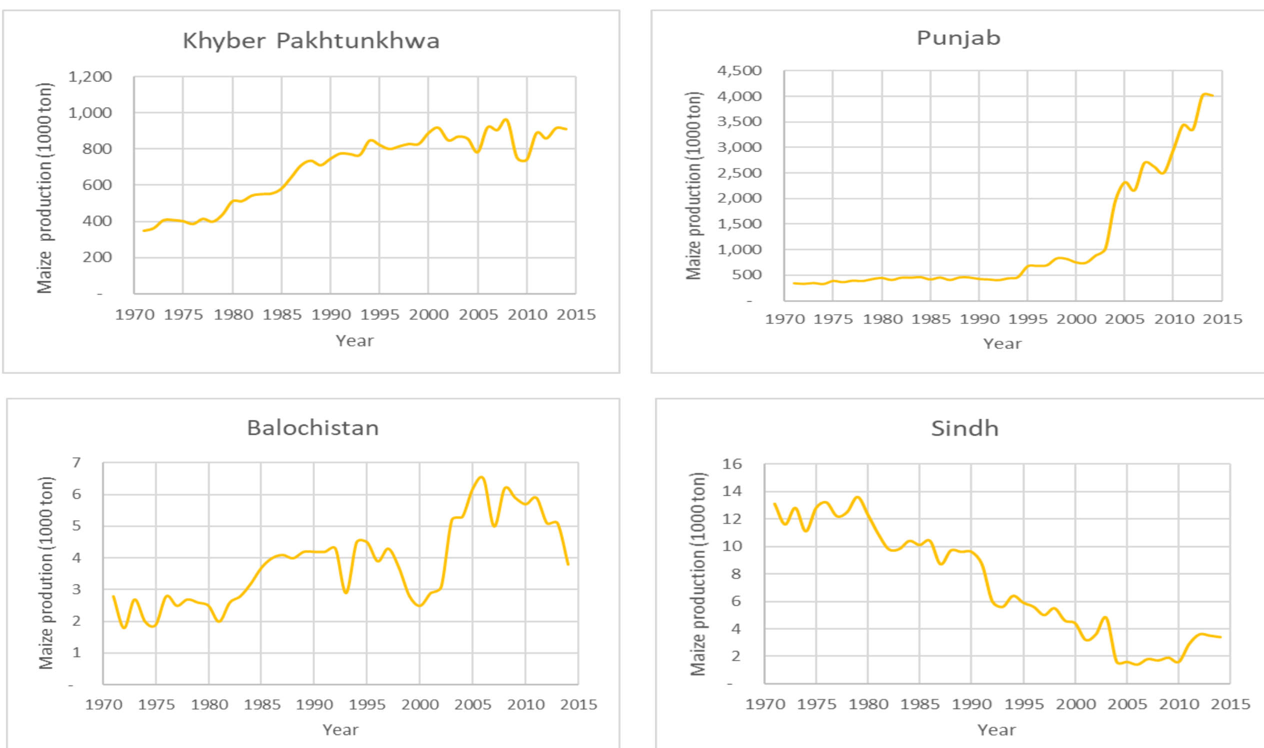


Figure 3.12 Provincial Maize production

CHAPTER 4: CORRELATION & GROWTH MODEL

Objective

The objective of this analysis is to create a correlation between the crop production and drought and determine its significance. Change in the production from previous year is a result of area effect, yield effect and interaction effect as shown in equation (4.1). Both yield and harvesting area are affected by drought, so significance of correlation would mean that change in production is directly impacted by drought, which can be positive or negative depending on value of SPI.

$$\Delta P = \underbrace{A_o*\Delta Y}_{\text{Yield effect}} + \underbrace{Y_o*\Delta A}_{\text{Area effect}} + \underbrace{\Delta A*\Delta Y}_{\text{Interaction effect}} \quad (4.1)$$

In order to generate a correlation, we need a production model which would include time trend and drought factors. The same model will be used for carrying out the regression analysis to check significance of drought at seasonal level production and on individual crop production. So the first thing to be done is to define a model which best fits Pakistan crop production data over time trend only and subsequently a drought factor in term of SPI will be added to it.

Existing Models

There are several existing models which are used to determine growth rate of crop production basing on the response variables with time. The most common and widely used among all is exponential model which gives a correlation between the crop variables and time trend but in this relationship the growth rate remains constant over the time. Model used to determine compound growth rate is given in equation (4.2).

$$P_t = P_o\,(1 + r)^t \quad (4.2)$$

Where P_t is crop production at any time t, P_o is initial production and r is compound growth rate. This model is linearized by using natural log and then used for the regression analysis to determine compound growth rate to generate a correlation between crop and time trend. This model being famous and common was considered initially but there are some short coming to this model which restricted it from giving a good fit to the Pakistan crop production data. One of the disadvantages of using this model is that it grows exponentially, and it may fit well initially when a lot of resources are available but if maximum resources are already in use then this model will not be a good fit. As already mentioned, that SAP influenced the growth rates post 88 and mostly the growth rates were reduced so when exponential or also known as Malthusian model was used it either underestimated or overestimated the predicted crop production.

The other models which were considered to generate a correlation between crops production data over time were monomolecular model and logistic model, which are relatively more realistic as the growth rates are not constant and depend on the capacity of the system and take into consideration of crowding phenomenon. Monomolecular model growth rate is maximum initially and decomposes with time when resource consumption reaches to the maximum. Logistic model behaves like an exponential model initially, when resources are available in abundance and subsequently when lesser resources are available, growth rate will slow down giving a S shaped distribution curve. Monomolecular model is shown in equation (4.3) and logistic model is shown in equation (4.4), where r is intrinsic growth, K is carrying capacity and P_o is P_t when t = 0 (Prajneshu & Chandran, 2005).

$$P_t = K - (K - P_o) \exp (-rt) \tag{4.3}$$

$$P_t = K / [1 + (K / P_o -1) \exp (-rt)] \tag{4.4}$$

These models were good fit to specific data sets available but with few limitations. The biggest disadvantage was that these models would not represent all the data sets of production and crop type universally at sub national level. The reason which was observed for failure to a generic representation was due the temporal variation within the different data sets as growth rate was positively increasing for some crops and was slowing down for other crops at sub national level due to the implementation of SAP in 1988.

Proposed Model

In order to find a model which best fits all the data sets for all crops at sub national level universally a second order model was used, and it was flexible enough to cover the temporal variation of growth rates for all the data sets. Once this model satisfactorily defined the data sets, drought factor in term of SPI was added to it. The model which was used for the analysis is shown in equation (4.5)

$$P = f\ (SPI, Time)$$

$$P_t = ßo + ß1 * SPI + ß2 * t + ß3 * t2 + \mathcal{E} \qquad (4.5)$$

P_t is the production at time t, SPI represent the drought factor in the model, t represents the time trend which accounts for the technology and improvement in agronomics resulting an increased production with time, ß coefficients are fitted to explain variance in production as a result of time trend & drought and Ɛ represents the residual error. F-test will be used to determine the significance ($p \leq 0.05$) of all the variables, and the most important will be the significance of SPI. This is a nonlinear model in term of time trend with more flexibility to capture the temporal variation within crop production unlike the models earlier discussed and drought in term of SPI is considered linear. Lobell et al (2011) has also used a nonlinear model in “Climate trends and global crop production since 1980” but he has observed the impact of temperature and precipitation on the crop yield. SPI was initially considered nonlinear as well in this model, but results showed it insignificant and subsequently the squared part was ignored.

Sensitivity Analysis

The data set which shows drought as a significant variable will be used for sensitivity analysis to check the relationship between the effect (residue) caused by drought and the drought (SPI). Model will be run twice for each data set, first without considering the effect of drought and second considering the effect of drought. Then difference between the two results (residue) will be plotted against the SPI to observe relationship between the two. Residue is shown in equation (4.6).

$$\text{Residue from model} = P_{t\,(\text{including drought})} - P_{t\,(\text{excluding drought})} \qquad (4.6)$$

CHAPTER 5: DROUGHT IMPACT ON RAINFED AND IRRIGATED CROPS

Methodology

6-month SPI for the provinces have been calculated for both seasons. Drought impact on seasonal production will be analyzed in the form of seasonal water footprint and drought impact on individual crops will be analyzed on their production data set directly.

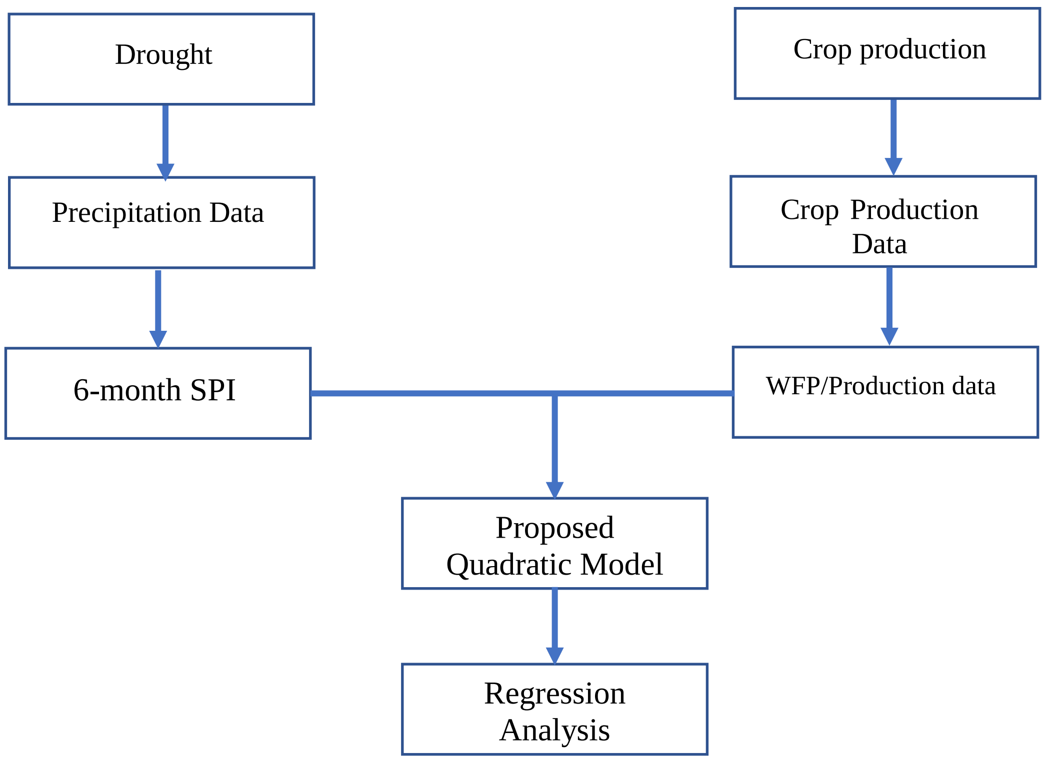


Figure 5.1 Methodology for the analysis.

Proposed second order model fits the existing data set of crop production for all provinces, regression analysis will be carried out on this model with the addition of drought factor in the form of SPI. The methodology is shown in fig. 5.1, results of the analysis will be discussed in two parts, first part will cover the results of correlation between the drought and seasonal production and second part will cover the correlation between the drought and individual crops.

Drought Impact on Seasonal production

Results of drought impact on seasonal production are discussed province wise.

Balochistan Province

Results of Rabi and Kharif season for Balochistan are shown in fig. 5.2 and fig. 5.3 respectively. Analysis shows a strong correlation exists between the drought and water footprint of the Rabi season with a P value of 0.015, however the predicted results by the model are unable to catch impact caused by extreme drought event of 1998-2002 entirely. There are some mild droughts as per SPI value but impact on the crop production seems to be extreme, as per 2009 drought value of SPI is > -1 categorized as a mild drought but reduction in crop production is apparently 40% from last year, so other complexities with in the crop production and drought phenomenon plays its part.

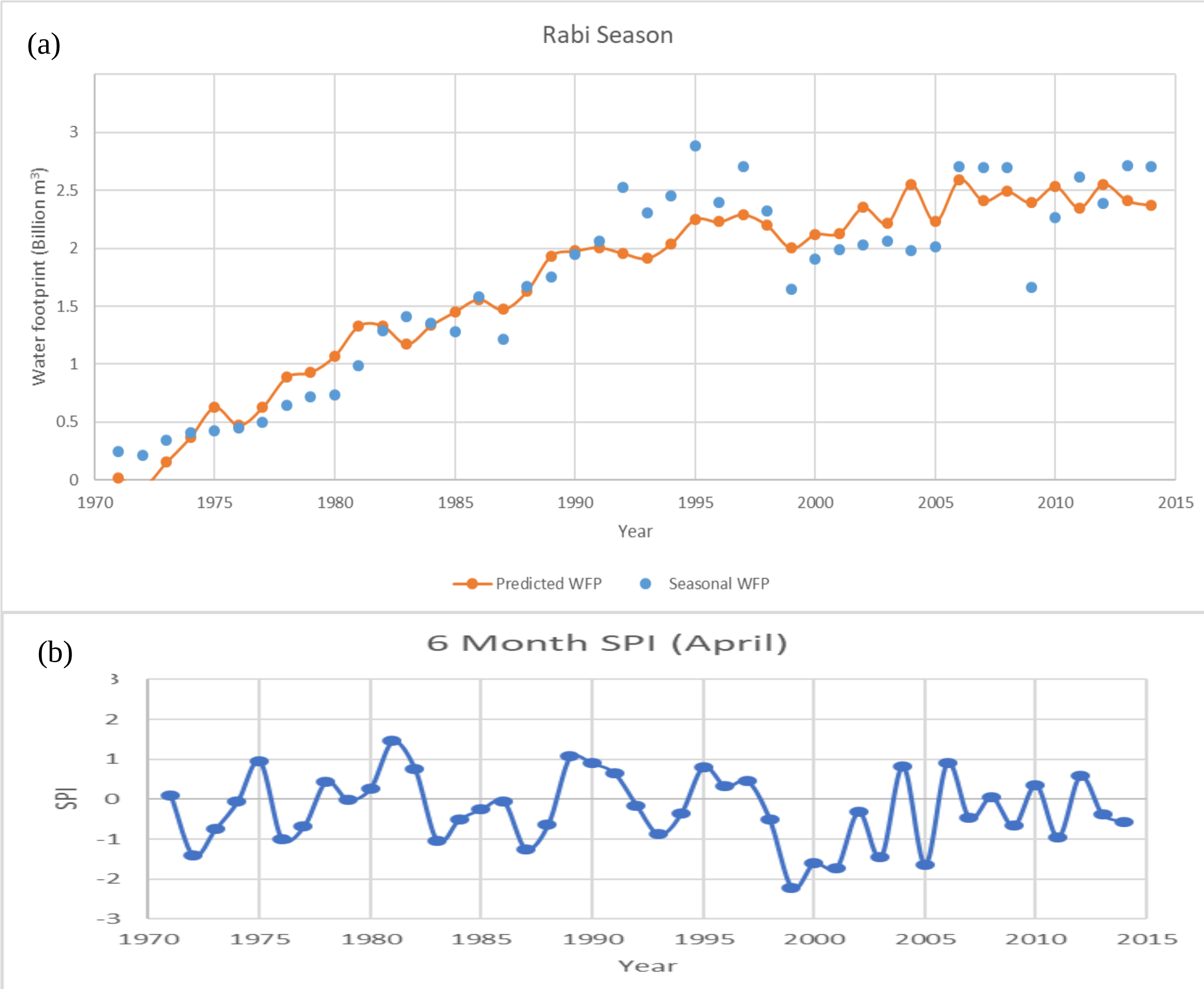


Figure 5.2 (a) Projected Water footprint for Rabi season of Balochistan province; (b) SPI results for Rabbi season from 1971 to 2014

Analysis for the kharif season doesn't show a correlation between the drought and water foot print of Kharif season. The major crop of Kharif season for Balochistan is rice as production of maize, sugar cane and cotton is negligble.

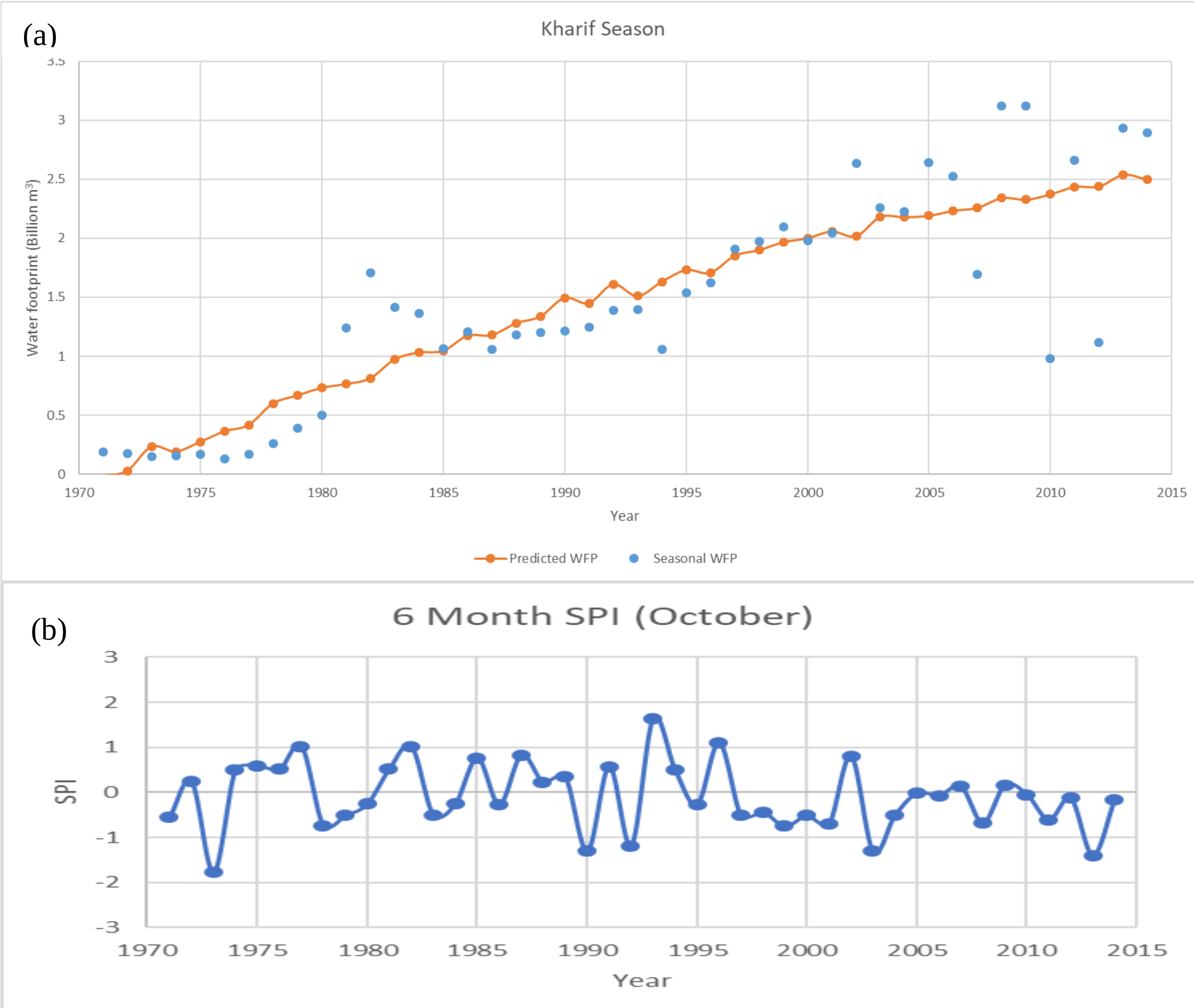


Figure 5.3 (a) Projected Water footprint for Kharif season of Balochistan province; (b) SPI results for Kharif season from 1971 to 2014

Khyber Pakhtunkhwa Province

Drought and water footprint of Rabi season for Khyber Pakhtunkhwa shows the strongest correlation with P value of 0.001. KPK is the only province with Rabi crop major share coming from the rainfed crop land and drought impact is evident on its production even for the mild droughts. Even with such a strong correlation model couldn’t cover the impact caused by the extreme drought event of 1998 to 2002. Other complexities like farmers decision based on experience, agronomics and other complexities play their part which is not covered by the model.

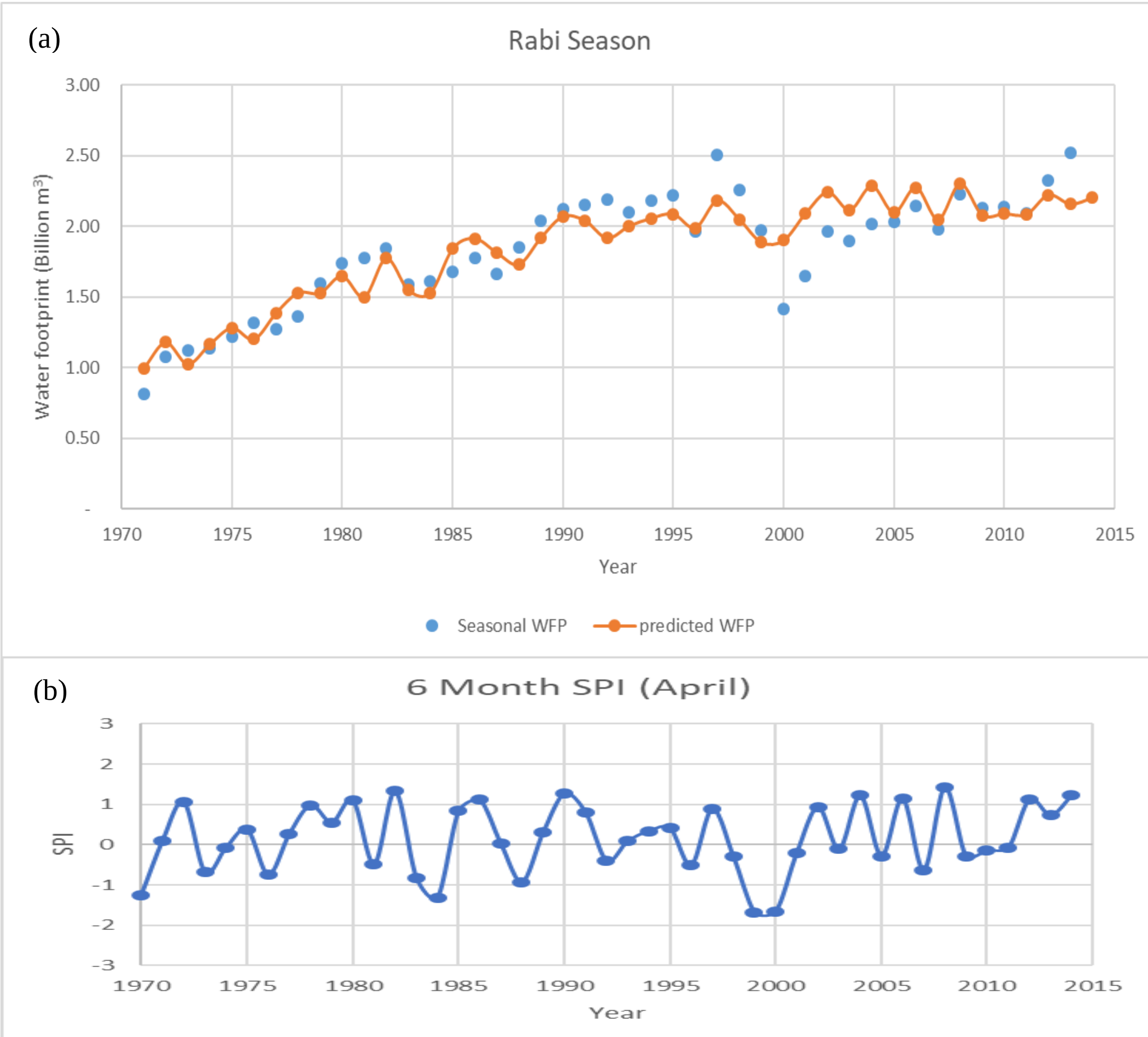


Figure 5.4 (a) Projected Water footprint for Rabi season of KPK province; (b) SPI results for Rabbi season from 1971 to 2014

No correlation exists between the drought and Kharif seasonal water footprint covering all the major crops for KPK as shown in figure 5.5. Kharif crops are water intensive less maize which is sown both on rainfed and irrigated crop land, so kharif crops are not vulnerable to the mild to moderate droughts.

Figure 5.5 (a) Projected Water footprint for Kharif season of KPK province; (b) SPI results for Kharif season from 1971 to 2014

Sindh Province

Sindh province didn't show a correlation between drought and Rabi or Kharif season water footprint. 98 % of wheat of Sindh is produced on irrigated crop land and all the Kharif crops are sown on irrigated crop land only, which makes this province very resilient to the mild to moderate droughts, 1998-2002 drought due to its prolonged nature impacted province crop production at seasonal level otherwise it has consistent growth.

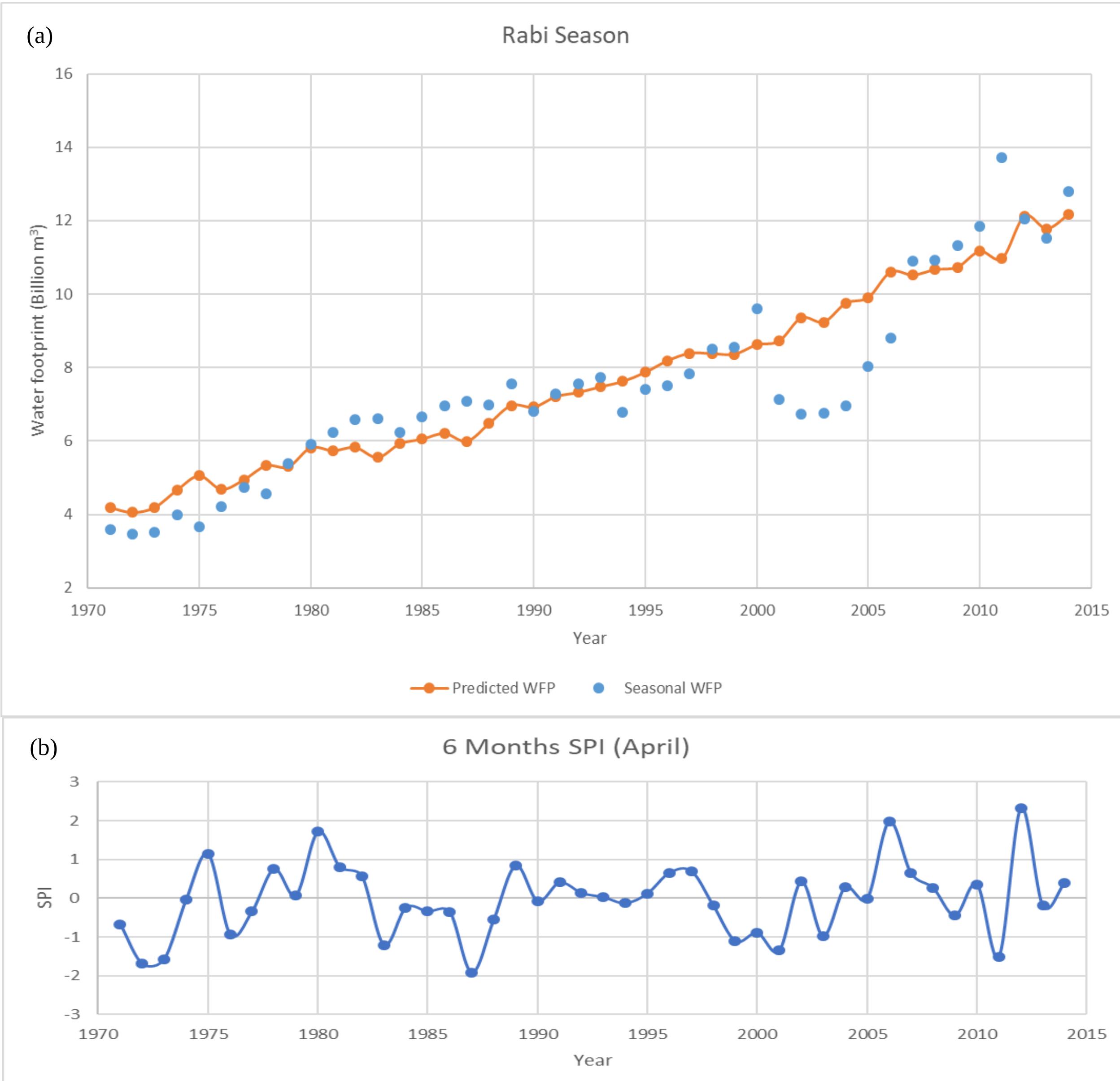
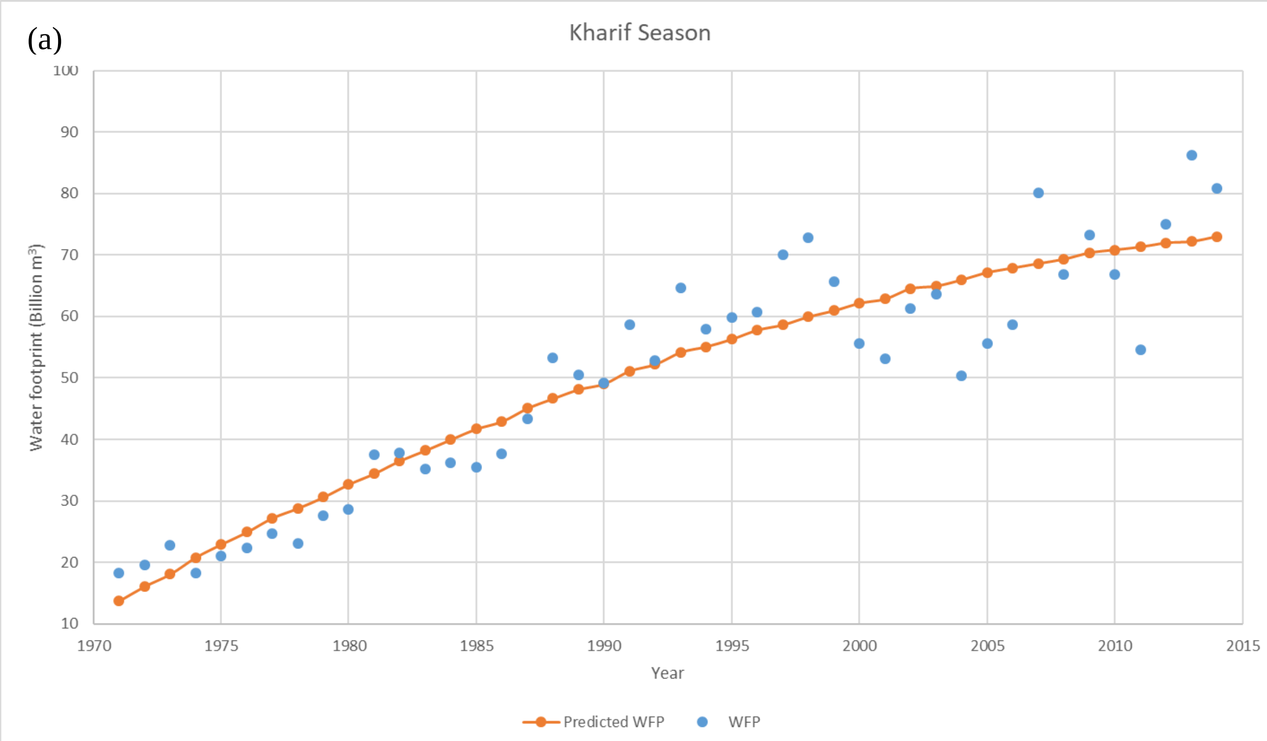


Figure 5.6 (a) Projected Water footprint for Rabi season of Sindh province; (b) SPI results for Rabbi season from 1971 to 2014



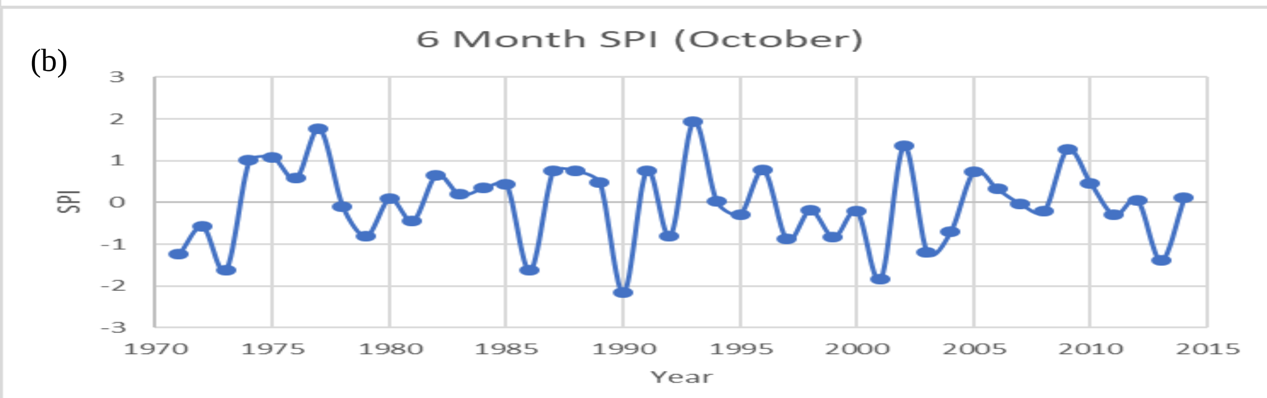


Figure 5.7 (a) Projected Water footprint for Kharif season of Sindh province; (b) SPI results for Kharif season from 1971 to 2014

Punjab Province

Punjab province didn't show a correlation between the drought and Rabi season / Kharif season water footprint. 95 % of wheat is produced from irrigated crop land and all the Kharif crops less maize are sown on irrigated crop land, so hug reliance on irrigation network and ground water makes this province very resilient to the mild to moderate droughts and even extreme drought of 1998-2002, which affected all other provinces. Drought events can clearly be observed in figure 5.8 and figure 5.9 but their impact on crop production is negligible.

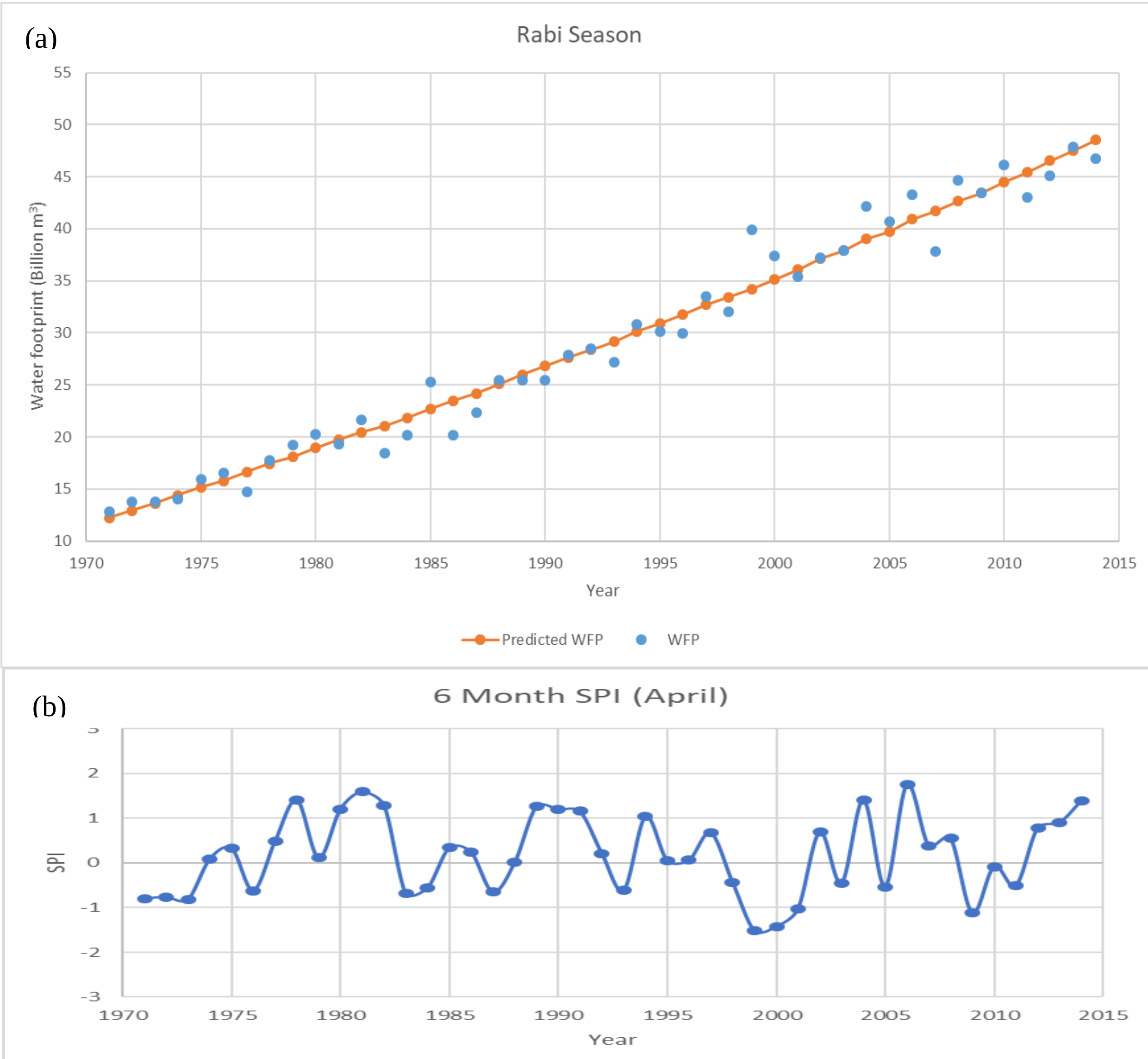


Figure 5.8 (a) Projected Water footprint for Rabi season of Punjab province; (b) SPI results for Rabbi season from 1971 to 2014

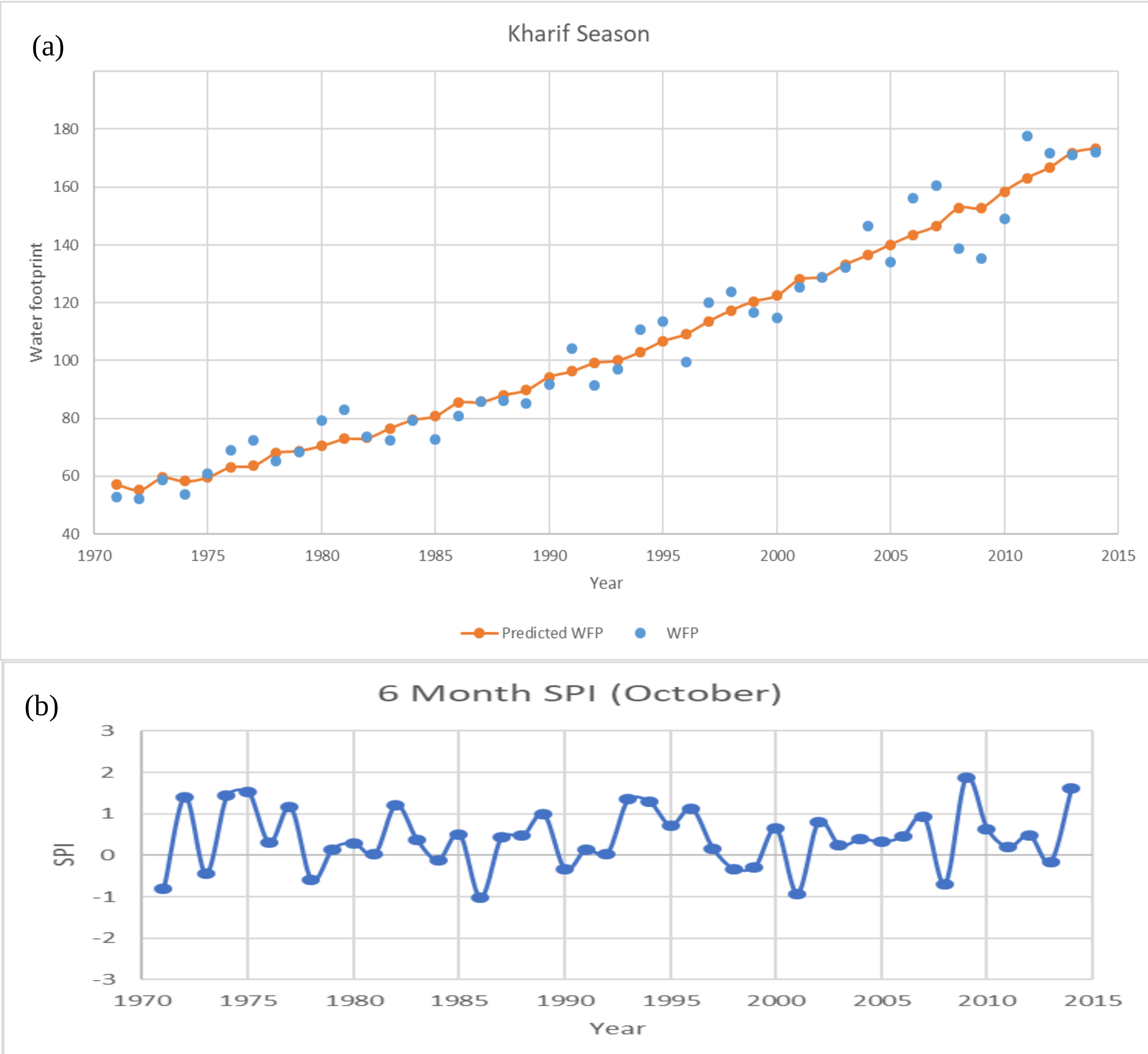


Figure 5.9 (a) Projected Water footprint for Kharif season of Punjab province; (b) SPI results for Kharif season from 1971 to 2014

Drought Impacts on Crops

Regression analysis was carried out to see any correlation between the crop production and drought for all the major crops at sub national level. Results are shown and discussed crop wise as under.

Wheat Production

Balochistan and KPK shows a strong correlation between the drought and wheat production with an R^2 of 0.87 & 0.80 and a P value < 0.05 for SPI, whereas Sindh and Punjab don’t show a correlation between the drought and wheat production, R^2 and P values for all the provinces are given in table 5.1. Wheat is a crop which is sown both on rainfed and irrigated crop land, 90% of wheat is produced from irrigated cropland and 10 % from rainfed crop land in Pakistan, KPK reliance on rainfed crop land for wheat production is the highest, according to Ministry of National Food Security and Research harvested rainfed area of province is 57 % which produces a 41.9% of provincial production. Other provinces reliance is mainly on the irrigation cropland, which makes them less vulnerable to drought and yet Balochistan shows a strong correlation between drought and wheat production because of its arid climate and smallest share by harvested area of crop makes it vulnerable. Eastern provinces with abundance of natural resources and no laws for ground water pumping makes them resilient under current circumstances against drought. But with time consumption of resources and crowding will not only decelerate growth rate of eastern provinces but will make them vulnerable to the droughts.

Table 5.1 Significance (P-value) of all variables for wheat production

Provinces		Balochistan	KPK	Sindh	Punjab
R^2		0.87	0.80	0.84	0.97
P value	Intercept	3.915E-06	9.41E-06	0.132927	0.134145
	Year2	5.187E-06	1.14E-05	0.114638	0.089611
	Year	4.496E-06	1.03E-05	0.123707	0.110437
	SPI	0.0153107	0.001021	0.193726	0.775029

Rice Production

No correlation was found between drought and rice production for any province. Rice is a water intensive crop and is sown on irrigated crop land and major shareholders are Punjab and Sindh, so this crop is not vulnerable to mild to moderate drought. Values of R^2 and P for all the provinces are given in table 5.2

Table 5.2 Significance (P-value) of all variables for rice production

Provinces		Balochistan	KPK	Sindh	Punjab
R^2		0.67	0.82	0.46	0.87
P value	Intercept	0.021440047	2.77E-10	0.135286	0.000109
	Year2	0.023920604	3.1E-10	0.127224	8.25E-05
	Year	0.022631719	2.92E-10	0.131359	9.53E-05
	SPI	0.5852841	0.895062	0.712418	0.857502

Cotton Production

No correlation exists between drought and cotton production for any province. Cotton in Pakistan is sown on irrigated crop land and major shareholders are Punjab and Sindh province, so this crop is not vulnerable to mild to moderate drought. Values of R^2 and P for all the provinces are given in table 5.3

Table 5.3 Significance (P-value) of all variables for cotton production

Provinces		Balochistan	KPK	Sindh	Punjab
R^2		0.78	0.15	0.84	0.78
P value	Intercept	0.001566	0.389346	4.61E-05	0.013265
	Year2	0.001311	0.396345	3.62E-05	0.015626
	Year	0.001434	0.392938	4.1E-05	0.014381
	SPI	0.579158	0.292275	0.390142	0.579641

Sugar Cane production

No correlation exists between drought and sugar cane production for any province. Sugar cane in Pakistan is sown on irrigated crop land and major shareholders are Punjab, Sindh and KPK province. Values of R^2 and P for the analysis of all the provinces are given in table 5.4

Table 5.4 Significance (P-value) of all variables for sugar cane production

Provinces		Balochistan	KPK	Sindh	Punjab
R^2		0.4	0.76	0.80	0.85
P value	Intercept	0.005826	0.005343	0.000113	0.001237
	Year2	0.006209	0.006232	0.000139	0.000973
	Year	0.006011	0.005744	0.000125	0.0011
	SPI	0.457583	0.990103	0.93619	0.67008

Maize Production

No correlation exists between drought and maize production for any province. Maize in Pakistan is sown on irrigated and rainfed crop land and major shareholders are Punjab and KPK province. P values from the analysis of KPK shows some correlation between the drought and maize production of KPK but not strong enough to make SPI significant. Production of maize for KPK is from both rainfed and irrigated crop land but their shares couldn't be ascertained. Values of R^2 and P for the analysis of all the provinces are given in table 5.5

Table 5.5 Significance (P-value) of all variables for maize production

Provinces		Balochistan	KPK	Sindh	Punjab
R^2		0.61	0.93	0.90	0.93
P value	Intercept	0.729145	1.19E-08	0.241529	7.44E-16
	Year2	0.761129	1.78E-08	0.289273	5.55E-16
	Year	0.744677	1.44E-08	0.264915	6.43E-16
	SPI	0.433712	0.171646	0.404168	0.995037

Sensitivity Analysis

Among the major crops' wheat showed strong correlation with drought for western provinces and Maize showed weak correlation with drought for KPK province only, so sensitivity analysis will be carried out for wheat crop only. To study the relationship between the drought and the residue in wheat production caused by it, model projected production including and excluding drought impacts are plotted in figure 5.10 and figure 5.12 for Balochistan and KPK provinces respectively will be used to determine the residue.

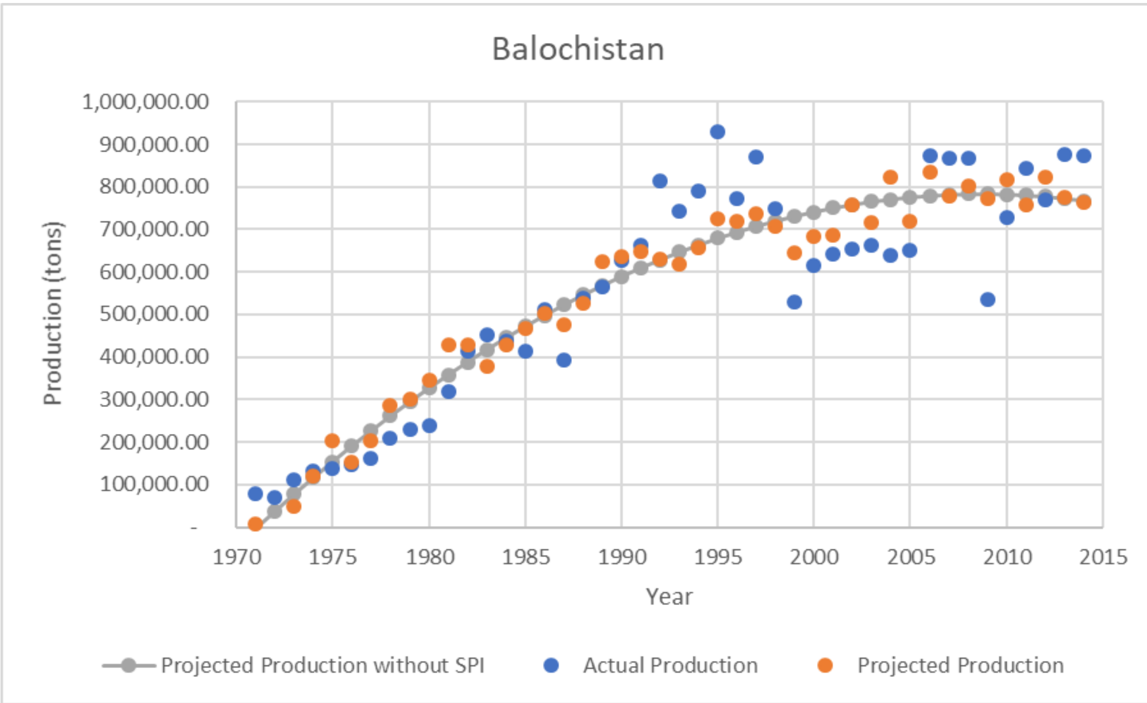


Figure 5.10 Projected wheat production for Balochistan including and excluding the impact of drought.

Residue in wheat production is plotted against the SPI of their respective provinces as shown in figure 5.11 and figure 5.13 for Balochistan and KPK provinces respectively. The relationship is positive which is intuitive as a positive SPI means more than normal rains should have a positive impact on the wheat production and negative SPI means less than normal rains should have a negative impact on the wheat production.

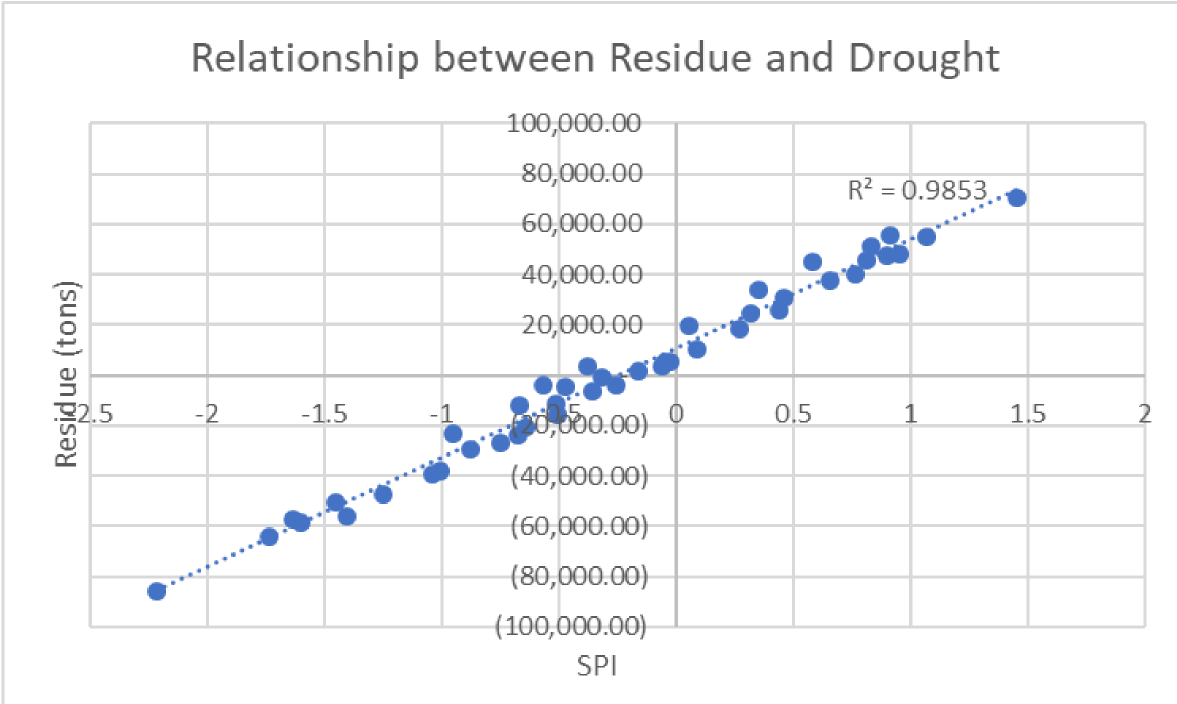


Figure 5.11 Relationship between residue in wheat production and SPI for Balochistan

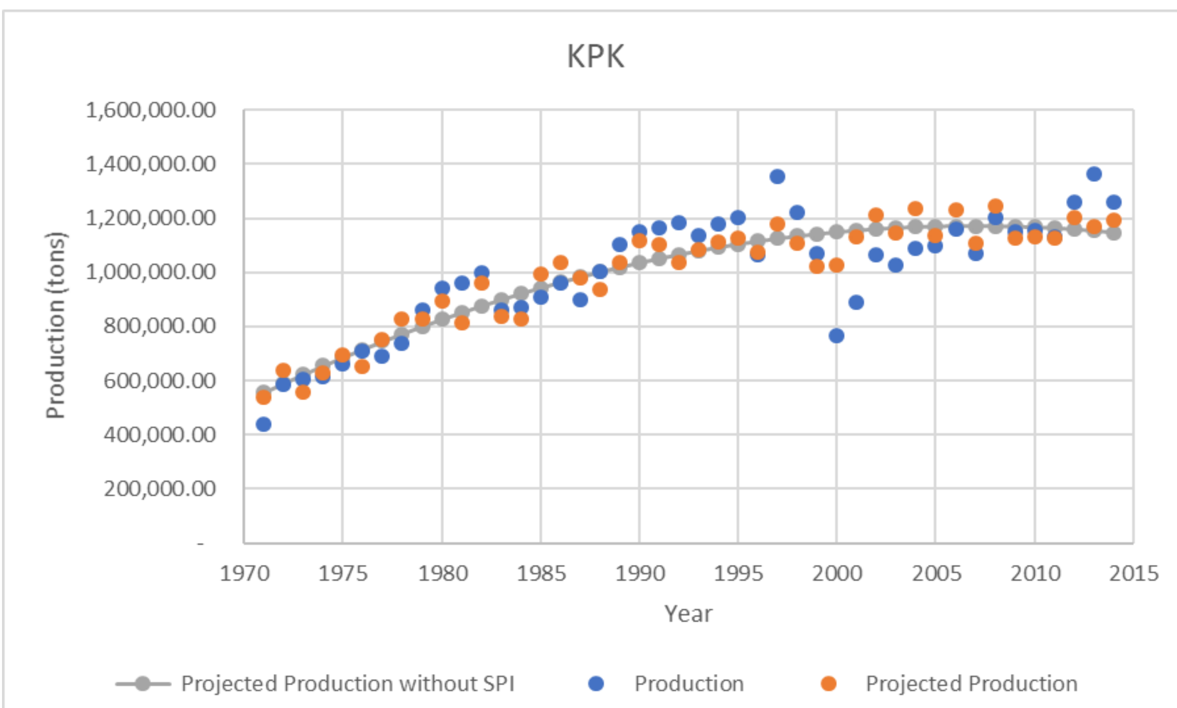


Figure 5.12 Projected wheat production for KPK including and excluding the impact of drought.

In figure 5.11, x-intercept for the Balochistan province is -0.25, which can be defined as critical SPI for the province. SPI value below the critical SPI will start affecting the crop production negatively. Critical SPI for KPK provinces is + 0.2 and drought negative impacts on production will start below this threshold as shown in figure 5.12.

Comparing the critical SPI of the two provinces gives some insight in the mechanics of crop production. Balochistan although representing the smallest portion of country wheat production is dependent mainly on irrigated crop land and a drought of mild category will be buffered, whereas KPK dependence on rainfed cropland is higher and system cannot even absorb a mild drought.

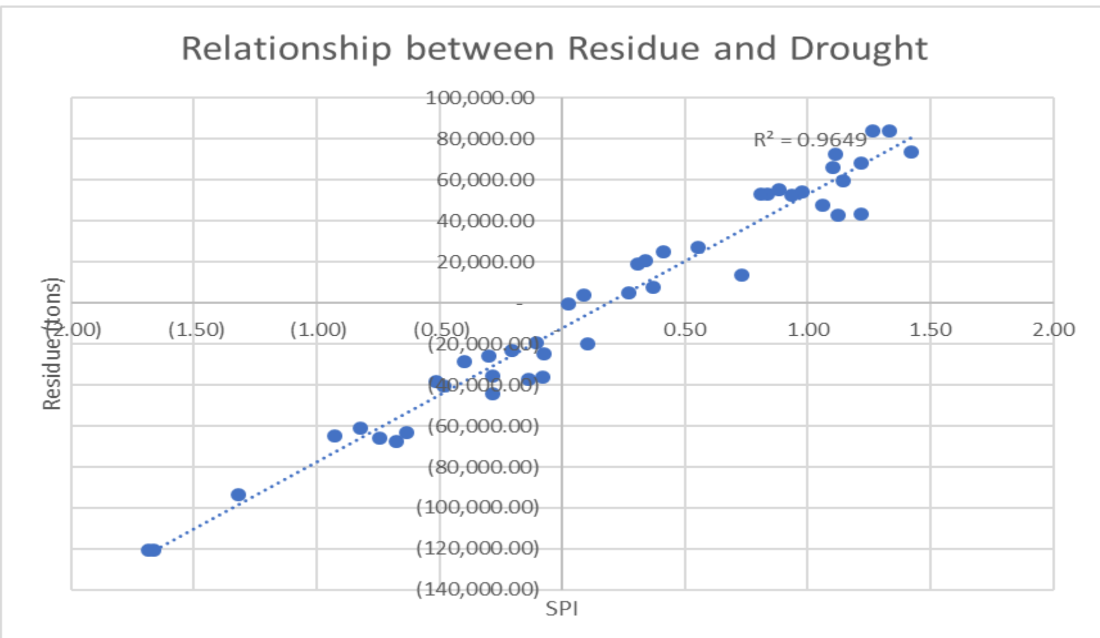


Figure 5.13 Relationship between residue in wheat production and SPI for KPK.

CHAPTER 6: CONCLUSION & RECOMMENDATIONS

Conclusion

The impact of drought on the crop production in Pakistan is studied by generating a correlation between the drought/ time trend and the crop production. Comparing crop production with yield brings in additional complexity in the form of changing harvesting area, thus making it more realistic to see the overall impact of drought on the system. Drought analysis of the all the provinces shows that Kharif season has lesser dry periods than the Rabi season making kharif season crops less vulnerable. Analysis shows that correlation exists between drought and Rabi crops and no correlation exists between the drought and Kharif crops.

KPK's wheat production reliance on the rainfed crop land is higher and shows a stronger correlation between its production and the drought. Balochistan represents the smallest share of country's total wheat production and its reliance for the production is on irrigated cropland because of its arid climate but shows a stronger correlation between its production and the drought. Punjab and Sindh didn't show any correlation between wheat production and their respective droughts because of the abundance of natural resources and no laws on ground water pumping, which is done extensively in case of limited surface water supply due to drought.

All the major crops of the Kharif season, which includes rice, cotton, sugar cane and maize did not show any correlation between their production and drought. In Pakistan, rice, sugar cane, and cotton are preferably sown in areas where water is supplied through irrigation and supplemented by rainwater and ground water, hence they are less vulnerable to the mild and moderate drought. In case of extreme or prolonged drought, the water shortage effect can be seen on crop production, but that is not caught by the regression analysis. Maize is a crop which is sown both on rainfed and irrigated cropland and the main producers of this crop are Punjab and KPK and no correlation is found between maize production and the drought in the two provinces.

The proposed model was successful in predicting the effects of mild to moderate droughts on the crop production but could not catch the impact completely for extreme or prolonged droughts. A strong relationship between the drought and its impact (residue) on crop production was found, as positive SPI will change the crop production positively and negative SPI will change the crop production negatively. Critical SPI and below starts affecting the crop production and the variation in it could be caused by temperature, agronomics and type of water used within the system.

Recommendations

One of the limitations of this study is duo to non-availability of crop production data at the district level for a longer period, and SPI is averaged out at the provincial level to carry out the analysis with the available crop production data. The scale of the model has a great impact on the results as averaging out SPI at the provincial scale with inherent spatial variation might has affected the outcome. Analysis at the district level is expected to provide better results and more insights.

The quality of data is another issue and detailed information about the rainfed, and irrigated crop production fraction is s not available for the crops which are sown on both type of crop land. Analysis of crops should be carried out based on the source of water they use, which would provide a comparison of drought impacts on the rainfed and irrigated crop land.

Instead of five major crops only wheat and maize should be further studied at district level with the classification of rainfed and irrigated crop land to get more insights and comparative results of drought impact on their production.

In the existing model, SPI is a linear variable which successfully predicts mild to moderate droughts but cannot capture severe to extreme droughts. Therefore, it should be experimented with to capture severe to extreme droughts.

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APPENDIX A: AVERAGE PROVINCIAL SPI

	BALOCHISTAN		KPK		SINDH		PUNJAB	
YEAR	RABI	KHARIF	RABI	KHARIF	RABI	KHARIF	RABI	KHARIF
1971	0.088324	-0.55474	0.102686	0.361034	-0.66682	-1.23392	-0.79871	-0.81237
1972	-1.40549	0.245816	1.061289	0.351219	-1.69199	-0.57116	-0.75905	1.404169
1973	-0.75071	-1.77317	-0.67715	-0.02636	-1.56581	-1.60898	-0.81911	-0.44899
1974	-0.05687	0.508904	-0.07553	0.724004	-0.03242	1.009374	0.082378	1.440084
1975	0.954332	0.596176	0.372297	0.678558	1.139969	1.089326	0.333789	1.536716
1976	-1.00527	0.512997	-0.74411	0.310362	-0.92787	0.582498	-0.62031	0.302711
1977	-0.67613	1.019755	0.272108	0.226089	-0.34032	1.771302	0.486813	1.159063
1978	0.439033	-0.74362	0.976337	0.505964	0.751784	-0.09196	1.408223	-0.59795
1979	-0.02181	-0.5158	0.552547	0.917083	0.079134	-0.79867	0.111163	0.145961
1980	0.274319	-0.25569	1.101724	0.337905	1.716145	0.091211	1.203683	0.28774
1981	1.45599	0.520108	-0.48441	-0.46333	0.796292	-0.4316	1.591968	0.028272
1982	0.764237	1.018969	1.33006	0.500889	0.569553	0.657958	1.288919	1.211474
1983	-1.03502	-0.5035	-0.82078	0.676881	-1.20229	0.192503	-0.68824	0.36247
1984	-0.5055	-0.25477	-1.31748	-0.52794	-0.24299	0.340354	-0.55806	-0.11654
1985	-0.25393	0.760982	0.834529	0.688921	-0.34167	0.438843	0.339334	0.511039
1986	-0.04806	-0.27226	1.114158	0.502974	-0.34743	-1.62516	0.240135	-1.02677
1987	-1.24719	0.826247	0.024051	-0.07589	-1.91527	0.764537	-0.64769	0.44443
1988	-0.64115	0.22463	-0.92736	0.942663	-0.55064	0.757222	0.013068	0.468947
1989	1.071401	0.346619	0.308245	-0.13147	0.840425	0.468616	1.270031	0.986479
1990	0.898167	-1.30755	1.263964	0.294925	-0.07513	-2.15015	1.197824	-0.3379
1991	0.654057	0.575179	0.809025	0.438584	0.404837	0.766768	1.153783	0.14053
1992	-0.15696	-1.18335	-0.39591	0.283858	0.135886	-0.79559	0.214642	0.028546
1993	-0.87771	1.638832	0.087202	1.226245	0.026009	1.945662	-0.60989	1.350506
1994	-0.35819	0.493844	0.338576	1.143936	-0.12638	0.021355	1.035889	1.293879
1995	0.809857	-0.27467	0.413386	1.061639	0.123939	-0.28088	0.051279	0.71572
1996	0.319858	1.10323	-0.51294	0.626636	0.65441	0.777319	0.061479	1.124701
1997	0.460859	-0.51523	0.88493	0.641527	0.695316	-0.87894	0.671311	0.168093
1998	-0.51216	-0.44064	-0.29952	-0.42335	-0.19166	-0.18064	-0.43255	-0.32874
1999	-2.21465	-0.75137	-1.68526	0.048879	-1.10503	-0.82551	-1.51548	-0.28099
2000	-1.59558	-0.51363	-1.66416	0.125888	-0.89279	-0.20858	-1.42271	0.641701
2001	-1.73329	-0.69263	-0.20225	-0.39725	-1.34969	-1.83572	-1.03123	-0.92474
2002	-0.31675	0.809139	0.933318	1.009576	0.429172	1.354171	0.694025	0.795732
2003	-1.45074	-1.3076	-0.10706	0.158656	-0.97627	-1.18607	-0.45243	0.237171
2004	0.831902	-0.50711	1.218197	0.137683	0.286375	-0.70619	1.412373	0.388298
2005	-1.63351	-0.01739	-0.28519	0.588665	-0.01937	0.74089	-0.53443	0.322575
2006	0.913176	-0.06806	1.143742	0.414312	1.970969	0.326705	1.7487	0.455935
2007	-0.47042	0.132487	-0.63337	1.24316	0.641929	-0.02953	0.383467	0.926489
2008	0.058569	-0.67846	1.419197	-0.2842	0.267555	-0.2161	0.559574	-0.68972
2009	-0.66407	0.167348	-0.28484	2.610685	-0.44583	1.273677	-1.1195	1.870531
2010	0.35599	-0.04602	-0.139	0.264549	0.36026	0.458824	-0.08099	0.636469
2011	-0.94702	-0.6083	-0.08165	0.102648	-1.50166	-0.29613	-0.50765	0.191476
2012	0.583936	-0.13076	1.122454	0.710774	2.323166	0.052413	0.78138	0.485033
2013	-0.37797	-1.39907	0.732454	0.24503	-0.19393	-1.38691	0.901381	-0.16388
2014	-0.56337	-0.15397	1.219033	1.659017	0.397777	0.104535	1.386717	1.618883

APPENDIX B: MINISTRY OF NATIONAL FOOD SECURITY AND RESEARCH IRRIGATED AND RAINFED DATA

	IRRIGATED (AREA '000' HECTARES)						RAINFED (AREA '000' HECTARES)				
YEAR	PUNJAB	SINDH	KPK	BALOCHISTAN	PAKISTAN		PUNJAB	SINDH	KPK	BALOCHISTAN	PAKISTAN
2000	5464	1104.5	326.1	314.1	7208.7		716.3	39.7	480.4	17.9	1254.3
2001	5625.8	790.9	321.4	301.4	7039.5		629.7	19.8	468.9	23	1141.4
2002	5538.9	863.5	318.3	312.3	7033		562.9	11.7	428.6	21.3	1024.5
2003	5520.6	852.9	316.1	311.1	7000.7		576.7	10.8	416	29.7	1033.2
2004	5645.3	856.5	315.1	310.9	7127.8		610.2	21.7	426.5	30	1088.4
2005	5733.9	875.5	313.3	297.9	7220.6		645	11.9	435.3	45.2	1137.4
2006	5831	914.1	308.2	285.4	7338.7		652.4	19.1	413.1	24.6	1109.2
2007	5723	937	314	360.6	7334.6		709.8	45.2	440.3	48.3	1243.6
2008	5742.4	951.3	322.4	354.2	7370.3		659.6	38.6	425	56.3	1179.5
2009	6144.2	990.5	331.4	354.9	7821		692	40.9	438.1	54	1225
2010	6364.37	1044.8	338	328.3	8075.47		549.15	47.5	420.3	39.2	1056.15
2011	6001.8	1087.7	317.7	305.3	7712.5		689.2	56.7	406.8	35.5	1188.2
2012	5788.11	991.5	309.3	350.6	7439.51		694.83	57.7	420	37.8	1210.33
2013	5852.05	1011.1	324	317.4	7504.55		659.22	47.3	403.3	45.8	1155.62
2014	6221.9	1071	352.4	338.6	7983.9		679.5	50.6	424.5	12.1	1166.7
2015	6277.3	1064.4	322.6	372.7	8037		702.7	42.9	410.2	12.7	1168.5
2016	6205.7	1114.9	343	371.5	8037		708.2	39.7	429.3	11.4	1168.5
Avg	5863.549	971.8882	323.1353	328.6588	7487.343		655.1412	35.4	428.6235	32.04706	1150.029
	IRRIGATED (PRODUCTION '000' TONS)						RAINFED (PRODUCTION '000' TONS)				
2000	15535.4	2945.8	635.4	529.5	19646.1		944.6	55.5	432.4	0	1432.5
2001	15082.5	2200.6	550	614.2	18447.3		336.5	25.9	214	0	576.4
2002	14191	2087	575.9	634.4	17488.3		403.4	14	314.6	6.2	738.2
2003	14599.4	2096.3	637.8	633.2	17966.7		755.6	12.9	426.6	21.5	1216.6
2004	14833.2	2145.5	600.6	634.1	18213.4		805.8	26.7	424.6	29.3	1286.4
2005	16259.3	2493.5	582.6	586.5	19921.9		1115.7	15.1	508.5	51.1	1690.4
2006	15892.9	2724.2	618.5	649.9	19885.5		883.1	26.1	482.1	0	1391.3
2007	16607.5	3331.6	633.8	816.7	21389.6		1245.5	77.6	526.6	55.4	1905.1
2008	14812.4	3382.5	634.4	804.9	19634.2		794.6	28.9	437.4	63.7	1324.6
2009	17406.1	3508.1	689.8	806.6	22410.6		1013.9	32.1	514.7	61.6	1622.3
2010	17487.7	3663.4	689.2	527.5	22367.8		431.3	39.7	463.3	8.7	943
2011	18125.4	4232.4	677.2	688.7	23723.7		915.6	55.5	478.6	40.4	1490.1
2012	17040.3	3716.3	658.7	799.4	22214.7		698.57	45.2	471.6	43.4	1258.77
2013	17704.86	3562.5	714.6	715.9	22697.86		882.14	36.2	543	52.2	1513.54
2014	18874.1	3960.2	779.4	835	24448.7		864.8	41.9	583.7	40.3	1530.7
2015	18251.9	3620.7	684.6	858.2	23415.4		1030	52	575.3	13.8	1671.1
2016	18475.8	3763.1	770.8	858.3	23868		1050.9	71.7	629.6	13	1765.2
Avg	16539.99	3143.159	654.9	705.4706	21043.52		833.6476	38.64706	472.1529	29.44706	1373.895

APPENDIX C: WATER FOOTPRINT OF MAJOR CROPS OF PAKISTAN

WFP PER TON OF CROP AT SUB NATIONAL LEVEL (M3/TON) (1996-2005)				
MAJOR CROPS	BALOCHISTAN	KHYBER PAKHTOONKHWA	PUNJAB	SINDH
APPLE	1439.7	952.3	1100.1	1385.3
APPRICOT	1171.2	770.2	906.3	1135.7
BANANA	2661.3	2221.5	2371.6	2730.1
CHILLI	7816.8	5756.5	6426.0	7584.4
CITRUS	1345.7	865.8	1047.6	1337.1
DATES	862.9	741.9	782.6	796.8
GARLIC	883.1	494.4	702.9	924.8
GRAPES	1088.2	877.1	941.2	1044.8
GUAVA	1231.2	851.5	993.8	1207.4
MANGO	1231.2	851.5	993.8	1207.4
ONION	571.7	319.0	454.8	599.6
PEACH	1763.1	1159.4	1364.3	1709.6
PEARS	1009.7	667.9	771.3	971.6
PLUMS	1370.6	906.6	1045.2	1318.2
POMEGRANATE	910.2	815.0	843.9	821.4
BAJRA	9660.4	7629.3	8263.6	10253.0
BARLEY	10356.9	7102.7	7668.8	9236.7
CASTORSEED	15433.1	10903.6	12979.3	14463.2
COTTON	10673.9	7483.1	8434.7	9985.2
GRAM	4901.8	2613.2	3576.0	5546.2
GROUNDNUT	4852.8	4680.0	4626.4	3261.5
JOWAR	6953.1	5032.8	5400.5	6429.2
LINSEED	6032.2	2844.3	4580.0	6478.2
MAIZE	4480.9	3041.1	2861.0	3656.0
MASH	4901.8	2613.2	3576.0	5546.2
MASOOR	13345.5	9333.8	9373.6	11862.7
MOONG	4901.8	2613.2	3576.0	5546.2
POTATO	407.1	270.7	301.9	359.7
RAPESEED	4096.4	2313.7	3153.7	2175.8
RICE	3914.3	2643.0	2970.2	3568.2
SEESAMUM	8487.0	4397.8	6624.8	9075.3
SUGARCANE	3026.8	2376.4	2635.9	3267.7
TOMATO	665.8	426.8	531.8	698.8
WHEAT	3103.2	1847.9	2423.8	3199.7